FISHERIES INVENTORY AND IMPACT ASSESSMENT FOR THE PROPOSED KEENLEYSIDE POWERPLANT PROJECT ON THE COLUMBIA RIVER, B.C.

Final Report
Prepared for

B.C. Hydro
Vancouver, B.C.

by

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This impact assessment is based on the "Keenleyside Powerplant Project Engineering Description" prepared in November 1982. Since that time, ongoing planning and design studies have resulted in some changes that would affect the project description. The principal changes are as follows:

- In-service date has changed from 1992 to 1994 and the optional in-service date of 1990 is no longer being considered.

- Installed capacity has changed from 210 MW to 180 MW with corresponding changes to powerhouse design.

The above changes have been incorporated in the report only where they would affect the results of the impact assessment.

PREFACE

This report is one of a series of reports dealing with the aquatic resources in relation to the proposed Keenleyside-Murphy Project. Detailed fisheries studies for the Murphy Creek Project were conducted by R.L. & L. Environmental Services Ltd. during 1980 and 1981. These have been reported in the document entitled "Fisheries Inventory and Impact Assessment in Relation to the Proposed Murphy Creek Development on the Columbia River, B.C." by Ash et al. (1981) and an addendum report entitled "Murphy Creek Fisheries Study Addendum Report - Summer/Fall 1981 Studies" by Ash and Luedke (1981). The present report deals specifically with the effects of the addition of the Keenleyside Powerplant Project to the Murphy Creek Project, with the intent that this report be read in conjunction with the Murphy Creek fisheries reports identified above. As a result, the duplication of baseline data and discussion of impacts relating to the Murphy Creek Project has been minimized.

Additional aquatic studies relating to the Keenleyside-Murphy Project have been initiated by B.C. Hydro since the preparation of the original draft of this report. These include a water quality and aquatic resource study to collect additional baseline information in the Columbia River between the Hugh Keenleyside Dam and Trail (conducted by R.L. & L. Environmental Services Ltd. during 1982-1984), a study to monitor fish entrainment at the Hugh Keenleyside Dam (conducted jointly by B.C. Hydro and R.L. & L. Environmental Services Ltd. during 1983-1984), and a detailed water quality study of the Columbia River below the Hugh Keenleyside Dam (conducted by B.C. Hydro 1983-1984).

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SUMMARY

B.C. Hydro has proposed including generating facilities at the Hugh Keenleyside Dam in conjunction with the Murphy Creek Project. Since it was recognized that the incorporation of power generation facilities in the Hugh Keenleyside Dam may affect the fisheries resource in the general area, R.L. & L. Environmental Services Ltd. was contracted to review existing information and assess the probable impacts of the development on the aquatic resources in the vicinity of the Hugh Keenleyside Dam.

INVENTORY OF AQUATIC RESOURCES

Existing information relating to the limnology and fisheries of Lower Arrow Lake is limited in scope since no detailed biological studies have been conducted in the waterbody. The information relating to Lower Arrow Lake was obtained primarily from reports of a short limnological study conducted in the fall of 1976 (B.C. Research 1977), creel survey reports (Lindsay 1978; Lindsay and Seaton 1978), and through discussion with the Regional Fishery Biologist and local residents.

Lower Arrow Lake is low in total ions, total dissolved solids, colour, turbidity, nutrients, and biological productivity. Based on limited data, it appears that the lake thermally stratifies during the warmer summer months, with the stratification breaking down during September. Dissolved oxygen levels remain high throughout the water column. The Bacillariophyceae (diatoms) dominate the algal communities. Dominant zooplankton species include both Copepoda (**Cyclops bicuspidatus, Diaptomus leptopus**), and Cladocera (**Daphnia pulex**). The benthic macroinvertebrate community is represented by annelids, chironomids, and pelecypods (**Pisidium**). Although **Mysis relicta** were introduced into Arrow Lakes Reservoir in 1968 and in the early 1970's to enhance fish production, no studies have been conducted to document their abundance or effect on fish production in the system.

The probable species assemblage of Lower Arrow Lake, based on a variety of existing information, is likely comprised of 18 species of fish. The relative abundance of the species could not be determined from existing data.

Creel surveys conducted by the B.C. Fish and Wildlife Branch indicate that kokanee, rainbow trout, and Dolly Varden are the most desirable species to anglers. In 1978, 86% of the angling effort on Lower Arrow Lake was directed at kokanee, while rainbow trout and Dolly Varden attracted only 14% of the angler effort. The catch rate for kokanee (May to August) was relatively high (0.91 fish/rod hour). Tributary spawning escapements of kokanee, rainbow trout, and Dolly Varden are estimated by the B.C. Fish and Wildlife Branch to be in the order of 550 000, 1400, and 600 fish, respectively. The lack of information on other species precludes the determination of their relative importance in Lower Arrow Lake.

The primary sources of existing information relating to the aquatic resources of the Columbia River below the Hugh Keenleyside Dam were the reports of the fisheries studies conducted for the Murphy Creek Project (Ash et al. 1981; Ash and Luedke 1981; B.C. Fish and Wildlife Branch 1981).

The Columbia River below the Hugh Keenleyside Dam has been identified as having the highest total dissolved gas (TDG) concentrations of 35 major rivers or lakes in British Columbia (Clark 1977). The high TDG concentrations occur when large volumes of water from Lower Arrow Lake are discharged through the sluiceway. Although the TDG levels caused by sluiceway discharge are high enough to cause mortalities to fish held in shallow water, the extent of mortalities in the upper Columbia River where fish can move into deeper water, is unknown.

Mysis relicta which are present in the Columbia River below the Hugh Keenleyside Dam originate in Lower Arrow Lake and are transported through the low level ports or the sluiceway of the dam. **Mysis relicta** may constitute an important food source for a variety of fish species in the Columbia River downstream of the Hugh Keenleyside Dam.

The section of the Columbia River between Castlegar and the Hugh Keenleyside Dam is extensively utilized by a variety of sport and non-sport fish species. A diversity of habitat types, and a supply of food organisms from Lower Arrow Lake, provide conditions conducive to fish rearing and feeding. The abundance of sportfish (primarily rainbow trout, Dolly Varden, kokanee, and

burbot) in the Columbia River above Castlegar, results in a large amount of angling effort (B.C. Fish and Wildlife Branch 1981).

The extent of use of the mainstem Columbia River between the Hugh Keenleyside Dam and Castlegar for spawning by salmonids (i.e., kokanee, rainbow trout, Dolly Varden) is unknown; however, it is expected to be limited by steep banks in many areas, scarcity of suitable gravel substrates, siltation in the low velocity shallow areas, large water level fluctuations, and high dissolved gas concentrations at various times throughout the year. Some localized areas of suitable substrate have been identified, but the extent to which these areas are utilized is not known.

The section of the Columbia River between Castlegar and the Hugh Keenleyside Dam likely is utilized extensively for spawning by forage and coarse fish species as indicated by the large populations of juvenile suckers, redside shiners, and other species. The shallow, vegetated nearshore areas are important rearing habitats for these species.

Kokanee were abundant in the upper section of the Columbia River (Castlegar to Hugh Keenleyside Dam) in 1980, and constituted a substantial portion of the angler catch. The source of the kokanee in the upper section of the river is not known for certain; however, the lack of young-of-the-year kokanee in the sampling catch, the limited amount of suitable spawning substrate in this section, and the similarity in morphologic and scale characteristics of the fish suggest that the kokanee below the Hugh Keenleyside Dam are recruited from Lower Arrow Lake. Displacement of other sportfish species (e.g., rainbow trout, Dolly Varden, etc.) out of Lower Arrow Lake via the Hugh Keenleyside Dam discharge is also likely; however, the numbers involved or their significance to the downstream sportfishery is unknown.

During the winter of 1980-81, a substantial reduction in kokanee abundance occurred, and the kokanee fishery in the spring of 1981 did not develop. The reasons for the decline are not known, but the decline may be due to a reduction in recruitment to the population from Lower Arrow Lake, or possibly due to mortalities from high total dissolved gas saturations.

EFFECTS OF DEVELOPMENT

The proposed Keenleyside Powerplant Project will involve the installation of three vertical axis Kaplan turbines and generators on the north bank of the Columbia River, between the existing discharge facilities and the Robson-Broadwater Highway. This project is proposed in conjunction with the Murphy Creek Project.

Two operating regimes have been considered for the Keenleyside Powerplant and Murphy Creek Projects. Under Regime 1, which approximates existing conditions, the only changes in the operation of the Arrow Lakes Reservoir and the Hugh Keenleyside Dam attributable to the generating facility would be the diversion of approximately 55% of the total annual discharge from the sluiceway and low level ports to the powerplant. Under operating Regime 2, the mean annual minimum Arrow Lakes Reservoir level would be increased by about 6.6 m (i.e., reduced drawdown). This would result in the diversion of approximately 73% of the total annual flow through the turbines.

Although the project design for the Keenleyside-Murphy Project has been based on operating Regime 2, there is no certainty that this regime would be in effect immediately following completion of the project since the operation of the system is controlled under the terms of the Columbia River Treaty. As a result, it has been assumed that there would be a period with the project operating under Regime 1.

The potential impacts of the Keenleyside Powerplant Project on aquatic resources are summarized in Table S1. Impacts are evaluated with respect to three major project development phases (i.e., design/pre-construction, construction, operation). Since no substantial differences in impacts are expected between Regime 1 and Regime 2 operation of the project, the impacts have not been separated by regime in the summary table. Impacts associated with design/pre-construction activities are expected to be of low severity, of short-term duration, and restricted in geographic scope. Construction impacts, although they potentially could be of moderate to high severity, will be of short-term duration and restricted primarily to the immediate vicinity and downstream areas. The major construction-related impacts may include reduced water quality as a result of sediment input or toxic material spills, fish mortality if

Table S1. Summary of major potential impacts of the Keenleyside Powerplant Project.

Phase	Potential Negative Impact	Severity[a]	Duration[b]	Geographical Distribution[c]	Potential for Mitigation[d]	Potential Positive Impact	Extent[a]	Duration[b]	Geographical Distribution[c]
Design/ Preconstruction	Increased suspended sediment levels as a result of terrain disturbance.	N-L	S	L	H				
	Increased angling pressure.	N	S	L	H				
Construction	Decrease in water quality.	L-M	S	L,I	M	Potential small increase in nutrients as a result of discharge of treated sewage and possible use of nitrogen based explosives.	L	S	L
	Decreased fish abundance resulting from increased angling pressure.	H	S	L,I	H				
	Mortalities from explosives.	U	S	L	M				
	Ancillary facilities. (borrow areas, spoil disposal sites).	L-M	S	L	H				
Operation[e,f]	Reduced recruitment to downstream areas due to turbine mortalities.	U	L	L,I	L	Decreased extent and duration of high total dissolved gas levels.	U	L	L,I
	Effect on entrainment of zooplankton including mysids.	U	L	L	L				

[a]Severity/extent ratings: H = high; M = moderate; L = low; N = negligible; U = uncertain.

[b]Duration: S = short term (less than 5 years); L = long term (greater than 10 years); U = unknown duration.

[c]Geographical distribution—distributional aspects (in terms of resource use) of impact: L = local; I = international (i.e., USA).

[d]Potential for mitigation of adverse effects: H = high potential; M = moderate potential; L = low potential; U = unknown potential; N = not necessary due to low severity.

[e]Assumes Keenleyside Powerplant Project operated in conjunction with Murphy Creek (el. 424 m) Project but does not address impacts of Murphy Creek Project.

[f]Differences in impacts between Regime 1 and Regime 2 operation of the project are not expected to be significantly different.

underwater explosives are used, and increased angling pressure from the localized population build-up. Some of these potential impacts (i.e., toxic spills, increased angling pressure, etc.), if they occur, could affect aquatic resources in the Columbia River system in the U.S.A. as a result of transport of deleterious or toxic materials down the Columbia River, or by affecting migratory populations of fish (e.g., studies have shown that there are movements of rainbow trout and walleye between the Columbia River within the study area, and Lake Roosevelt in the U.S.A.). Proper planning, the implementation of precautionary measures, and on-site monitoring would preclude most of the potential impacts, or ensure that the impacts are low in severity.

The operational phase of the project will have both beneficial and adverse impacts on the aquatic resources associated with it. The major adverse impact of the development will be associated with a likely small increase in mortality of fish passing through the turbines relative to the other discharge structures (i.e., sluiceway, low level ports, navigation lock). The significance of this impact and the resulting decrease in recruitment to the downstream fish populations is not known since no data are available relating to the extent, timing, or size distribution of fish displaced through the discharge structures. Based on mortality studies conducted elsewhere, the mortality of fish passing through the turbines at the Keenleyside Powerplant Project is expected to be low (i.e., possibly 5 to 10%),and therefore likely would result in only a small decrease in recruitment of fish to the downstream fishery.

The inclusion of generating facilities may affect the entrainment of zooplankton including **Mysis relicta**, which in turn would affect fish food availability below the dam. However, since the invert level at the entrance to the intake channel would not be substantially different from the sluiceway crest, and since the turbines generally will not be operating during a 2.5 month (Regime 2) to 5 month (Regime 1) period during most years, the effect of the development on zooplankton entrainment is expected to be negligible unless current patterns in front of the intake differ significantly from those in front of the sluiceway.

The passage of approximately 55 to 73% of the mean annual flow through the turbines (with less than 3% of the total annual flow discharged through the

sluiceways) is expected to have a beneficial impact on downstream fish populations by reducing total dissolved gas saturations. Since it is not presently known to what extent the high total dissolved gas levels in the Columbia River cause mortality or affect the growth rates of resident fish, it is not possible to quantify the likely benefits of the expected reduction of saturation levels as a result of inclusion of generating capacity of the Hugh Keenleyside Dam.

No significant adverse impacts on the limnology or fish population in Lower Arrow Lake attributable to powerplant operation are expected; however, operation of the Keenleyside Powerplant Project under Regime 2 may slightly increase biological productivity as a result of reduction of the annual drawdown.

SECTION 1
INTRODUCTION

1.1 BACKGROUND

The Columbia River, which originates from Columbia Lake, southeastern British Columbia, flows 760 km to the Canada-U.S. Border and ultimately drains into the Pacific Ocean at Portland, Oregon. Within Canada, the Columbia River descends 410 m (el. 810 to 400 m; B.C. Hydro 1982), and drains a surface area of 154 623 km^2 (Water Survey of Canada 1977).

After ratification of the Columbia River treaty between Canada and the United States in 1964, the Duncan, Mica, and Hugh Keenleyside dams were constructed on the Columbia River or its tributaries to lessen flood damage in the United States, and to increase power generation.

Construction of the Hugh Keenleyside Dam, which is located 7 km upstream from Castlegar at the outlet of Lower Arrow Lake, was completed in 1968. The Arrow Lakes Reservoir, which extends from the Hugh Keenleyside Dam to near Revelstoke, was constructed as a water storage project, to control runoff from a 36 500 km^2 drainage area (B.C. Hydro 1982). Although provisions for generating facilities at the Hugh Keenleyside Dam were investigated during the original design studies, it was decided not to include them in the initial project.

Since 1977, B.C. Hydro has been developing engineering designs and studying environmental effects of a power generating dam (Murphy Creek Project) located 3 km upstream from Trail, B.C. and 34 km downstream from the Hugh Keenleyside Dam. The proposed run-of-the-river reservoir would extend upstream to the Hugh Keenleyside Dam on the Columbia River and to the Brilliant Dam on the Kootenay River. Although three headpond elevations (el. 424, 427, 430 m) have been investigated, only the lowest level (el. 424 m) would permit a power generating facility to be economically constructed at the Hugh Keenleyside Dam (B.C. Hydro 1982). Since it appears that the Murphy Creek (el. 424 m) Project built in conjunction with generating facilities at Hugh

Keenleyside Dam would optimize power production while reducing the overall environmental and social effects of the project (in comparison to the higher Murphy projects), the two projects (i.e., Murphy Creek el. 424 m and Keenleyside Powerplant) were selected as the basis for further studies.

1.2 STUDY AREA

The study area, as outlined in the Terms of Reference, consists of all land and water below el. 500 m within 10 km of the Hugh Keenleyside Dam. In addition, the fisheries study area includes both Lower Arrow Lake and the Columbia River, south to Trail, B.C. (Figure 1.1). The latter area includes the proposed site for the Murphy Creek Reservoir.

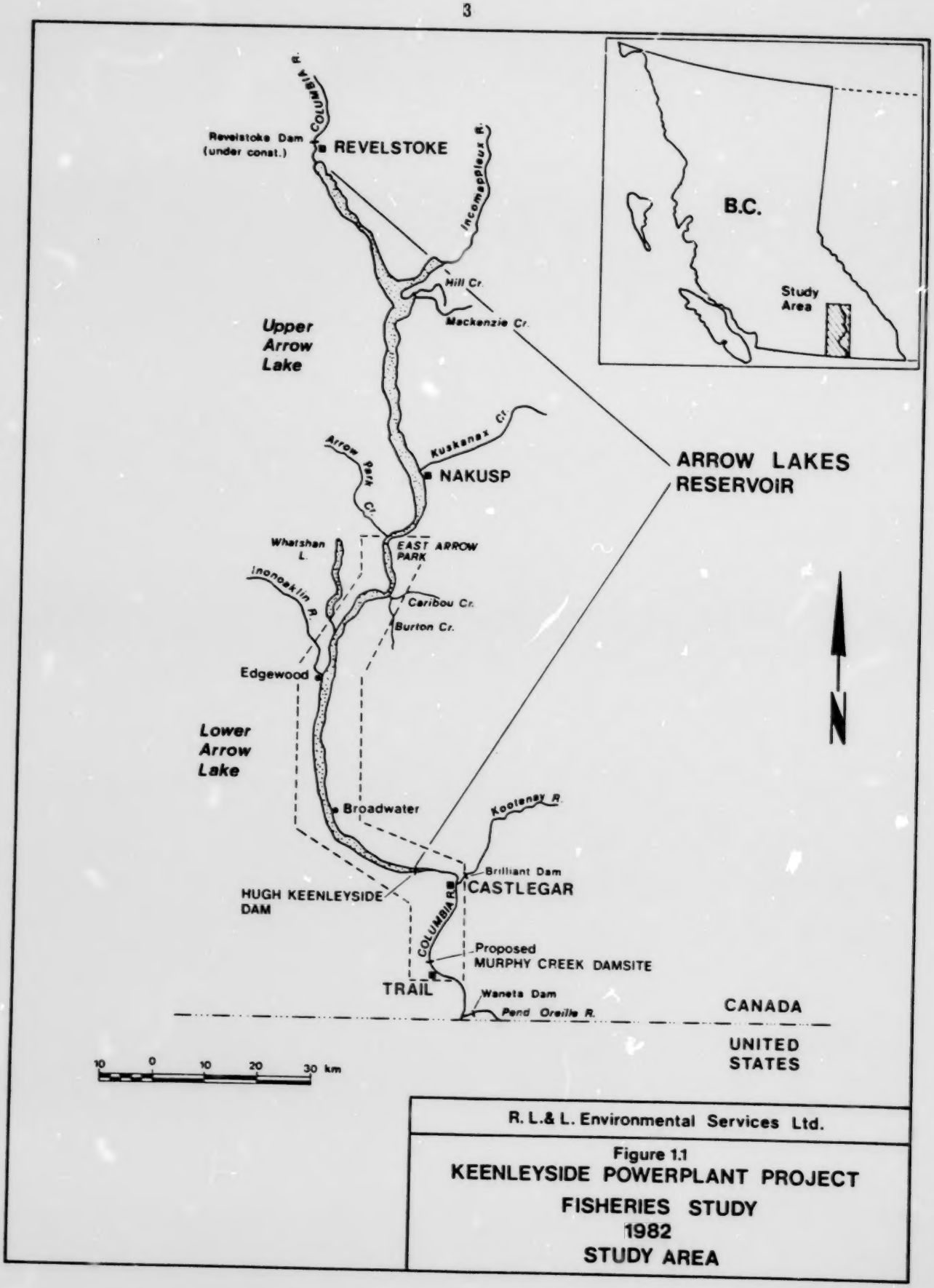
The Arrow Lakes Reservoir, which extends approximately 216 km, is separated into two waterbodies (i.e., Upper Arrow Lake and Lower Arrow Lake) by a small, narrow stretch of water near East Arrow Park (Figure 1.1). Lower Arrow Lake lies in a well-defined, generally steep-sided, narrow valley between the Monashee and Selkirk mountains. It is approximately 109 km in length (Hugh Keenleyside Dam to East Arrow Park), and has an average width of approximately 2 km (Lindsay and Seaton 1978). Below the Hugh Keenleyside Dam, the Columbia River flows east for a short distance before turning southward during the 57-km distance to the Canada-U.S.A. Border. It is generally confined to a single channel by the adjacent mountain ranges, and usually exhibits steep banks.

1.3 STUDY OBJECTIVES

The purpose of this study is to provide an assessment of probable incremental effects on the aquatic resources as a result of the addition of power generating facilities at the Hugh Keenleyside Dam to the Murphy Creek Project (headpond elevation of 424 m).

As outlined in the Terms of Reference, the three major objectives of this study are as follows:

(1) to describe potential changes to fisheries resources in Lower Arrow Lake and the proposed Murphy Reservoir (or Columbia River) resulting from the project;



R. L.& L. Environmental Services Ltd.

Figure 1.1
KEENLEYSIDE POWERPLANT PROJECT
FISHERIES STUDY
1982
STUDY AREA

(2) to determine whether or not further field studies are necessary; and

(3) to suggest mitigation measures with respect to fisheries and aquatic impacts.

Timing requirements for completion of the studies necessitated that the present study be based on existing sources of information. As noted above, one of the objectives of the study was to identify any data deficiencies, and to outline further studies that should be conducted to fill these deficiencies.

The specific Terms of Reference for the study as provided by B.C. Hydro are presented in Appendix A.

SECTION 2
METHODOLOGY

2.1 STUDY SCHEDULING

Authorization to proceed on the study was received in a letter from Dr. H.M. Etter, Manager, Environmental and Socio-Economic Services of B.C. Hydro, dated 17 March 1982. Scheduling requirements necessitated that the draft reports be completed in May of 1982. Comments on the initial draft report, and a revised project description, were received in February of 1983, and the draft report was revised and resubmitted in April of 1983. Additional comments and another updated engineering description were received in December of 1983, and the report was finalized in January of 1984.

2.2 SOURCES OF EXISTING INFORMATION

Background information pertaining to the aquatic resources of the Lower Arrow Lake and the Columbia River was obtained from a number of sources. The primary sources of information relating to the Columbia River and the proposed Murphy Creek Project were the fisheries inventory and impact assessment studies conducted by R.L. & L. Environmental Services Ltd. during 1980 and 1981 (Ash et al. 1981; Ash and Luedke 1981). Information relating to the limnology and fisheries of Lower Arrow Lake was obtained from a report by B.C. Research (1977) entitled "Limnology of Arrow, McNaughton, Upper Campbell, and Williston Lakes," and from B.C. Fish and Wildlife Branch unpublished reports and data (Lindsay and Seaton 1978; H. Andrusak, Regional Fisheries Biologist, Nelson, pers. comm.). Water quality data were obtained primarily from the B.C. Waste Management Branch. Information pertaining to the project description and engineering design was provided by B.C. Hydro.

Individuals in the various government agencies, in B.C. Hydro, or local residents who were contacted and who provided information used in this study include:

B.C. Fish and Wildlife Branch

- Mr. H. Andrusak, Nelson
- Mr. R. Lindsay, Nelson

B.C. Waste Management Branch

- Dr. R. Crozier, Nelson
- Dr. M.J.R. Clark, Victoria

B.C. Aquatic Studies Branch

- Mr. H. Singleton

B.C. Hydro

- Mr. H. Smith
- Mr. J. Mathers
- Mr. J. Muralt
- Mr. P. Maxymuik

Local Residents

- Mr. B. Salekin, Robson
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- Dr. G. Hunnisett

University of Victoria

- Ms. L. Gregory

Environment Canada, Inlands Water Directorate

- Dr. S. Sheehan

Monenco Consultants Pacific Ltd.

- Mr. D.P. Mahony

SECTION 3
INVENTORY OF AQUATIC RESOURCES

3.1 LOWER ARROW LAKE

B.C. Research (1980) conducted a limnological survey of Upper and Lower Arrow lakes as part of a comparative study of four British Columbia reservoirs. Additional information on the Arrow Lakes is available in the following reports: B.C. Fish and Wildlife Branch (N.D.); Lindsay (1976, 1978); B.C. Ministry of Environment (1977, 1979); Lindsay and Seaton (1978); and IEC (1981). The information on Lower Arrow Lake generally exists in segments of larger studies which focus on the lower Columbia River Basin. No single comprehensive study exists on the reservoir.

The following inventory is a synopsis of aquatic resources of the Arrow Lakes Reservoir. Where possible, information is provided specifically for Lower Arrow Lake; however, other information is provided for the Arrow Lakes Reservoir as a whole, since the appropriate parameters were not available specifically for Lower Arrow Lake (e.g., reservoir morphometry).

3.1.1 GENERAL LIMNOLOGY

3.1.1.1 Water Fluctuation

The original Arrow Lakes were inundated by the construction of the Hugh Keenleyside Dam in 1967. The storage reservoir created extends upstream from the Hugh Keenleyside Dam near Castlegar to Revelstoke. Lower Arrow Lake extends 109 km from the dam to East Arrow Park (Lindsay and Seaton 1978). The normal maximum water level of the reservoir is el. 440.1 m. A drawdown of up to 21 m occurs annually. The mean discharge from the reservoir at the Hugh Keenleyside Dam is 1150 m^3/s (B.C. Hydro 1982).

Under the obligations of the Columbia River Treaty, the Arrow Lakes Reservoir water level must be drawn down each year to provide a storage capacity of up to $8.8 \times 10^9 m^3$ for flood control purposes to protect downstream areas (B.C. Hydro 1982). The low water level generally is achieved by April, after which the level gradually increases to near the full supply level (el. 440 m) in midsummer. Elevated water levels are maintained until January.

3.1.1.2 Morphometry

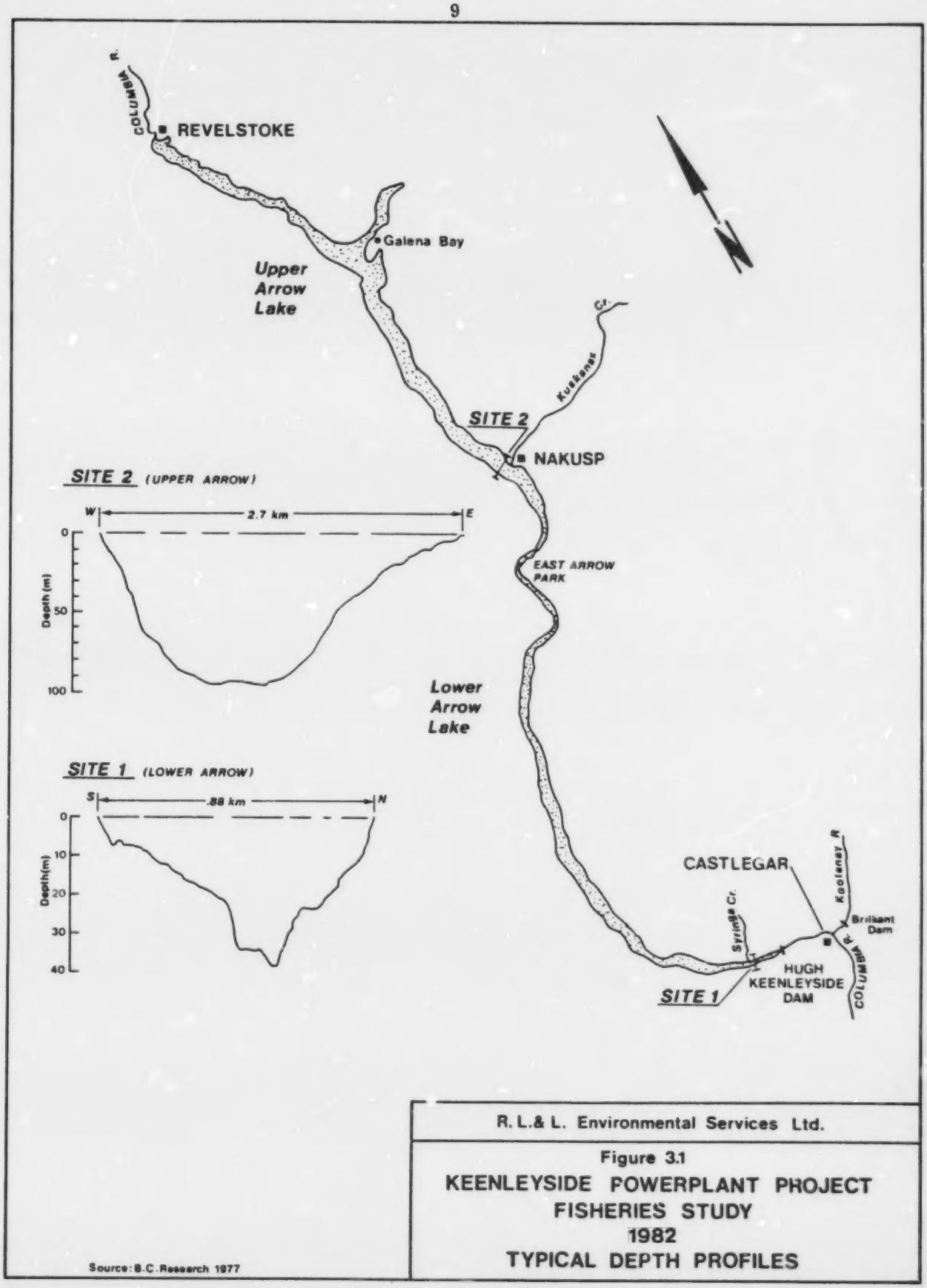
A summary of morphometric characteristics for Arrow Lakes Reservoir based on data collected by B.C. Research (1977) is presented in Table 3.1. The maximum depths for Lower and Upper Arrow lakes are 40 m and 130 m, respectively. The total surface area of Arrow Lakes Reservoir is $518 \times 10^6 m^2$. Shoreline development, an index reflecting the irregularity of the basin, is large (6.29) (i.e., the length of the shoreline is large compared to the surface area). A representative cross-sectional depth profile for each of Upper and Lower Arrow lakes is presented in Figure 3.1.

Table 3.1. Morphometry of Arrow Lakes Reservoir. (Source: B.C. Research 1977.)

Area (m^2)	518×10^6
Volume (m^3)	9250×10^6
Mean depth (m)	17.9
Maximum length (km)	216
Shoreline development	6.29
Flushing rate (years)	0.26

3.1.1.3 Physical/Chemical Parameters

During the 1976 fall sampling program in Lower Arrow Lake, B.C. Research (1977) did not detect any well-defined thermocline although a gradual temperature gradient existed (Figure 3.2). On 14 September 1976, water temperature decreased from 14.1°C (surface) to 11.1°C (28 m). Water temperature varied little with depth (7.7° to 6.6°C) on 25 November 1976 (Appendix B, Table B-1). Temperature data collected by the B.C. Ministry of Environment during 1980, however, showed that Lower Arrow Lake thermally stratifies during July and August (Figure 3.2; Appendix B, Table B-2). The thermocline on 21 July was located at a depth of between 13.7 and 19.8 m (i.e., decrease from 17.2° to

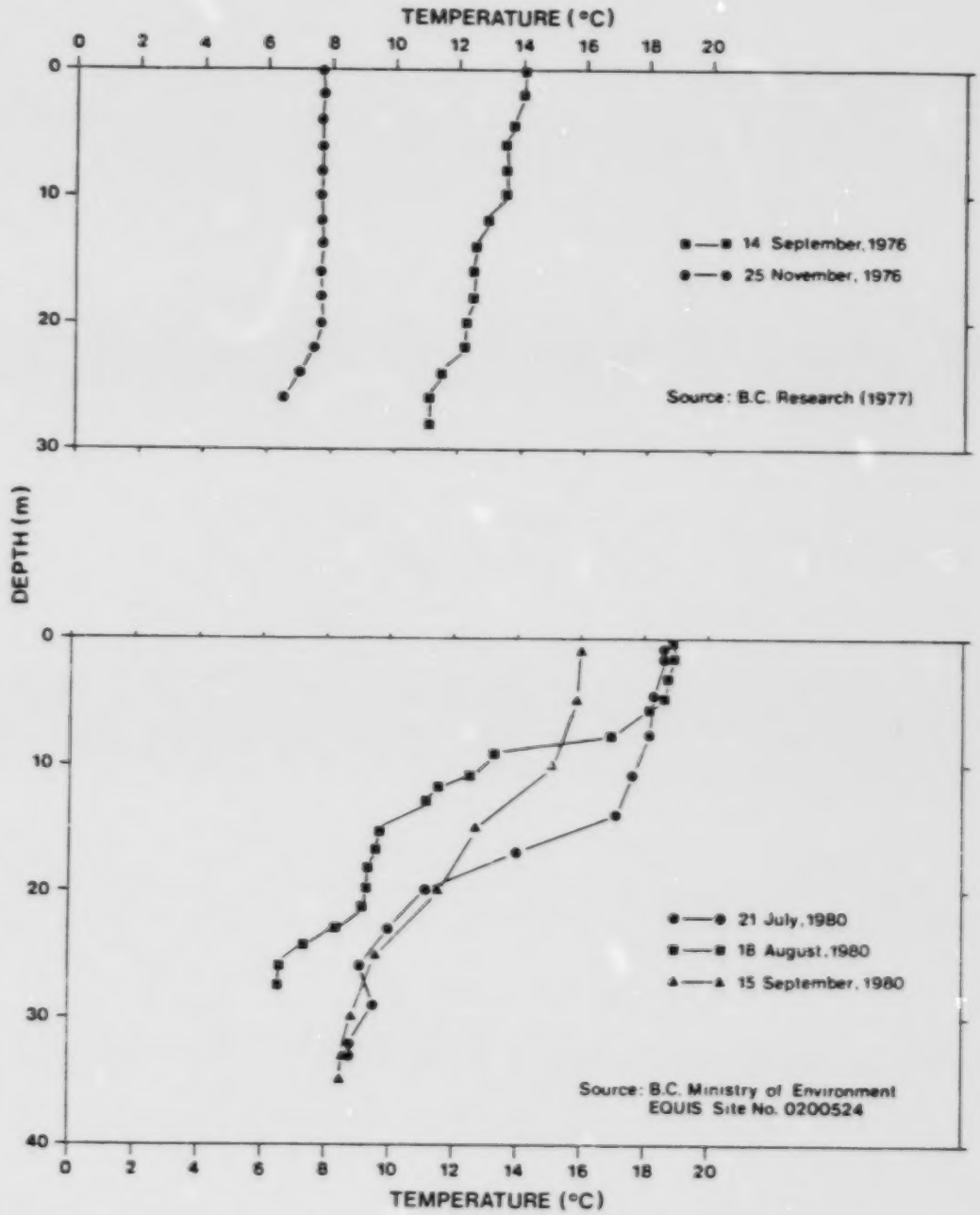


Source: B.C. Research 1977

R. L.& L. Environmental Services Ltd.

Figure 3.1

KEENLEYSIDE POWERPLANT PROJECT
FISHERIES STUDY
1982
TYPICAL DEPTH PROFILES



R.L.&L. Environmental Services Ltd.

Figure 3.2

KEENLEYSIDE POWERPLANT PROJECT
FISHERIES STUDY
DEPTH-TEMPERATURE PROFILES
LOWER ARROW LAKE NEAR SYRINGA CREEK

11.2°C). On 18 August 1980, the thermocline was more pronounced and was located at a depth of between 6.1 and 9.1 m (i.e., decrease from 18.2° to 13.3°C). During the fall sampling period (15 September 1980), no well-defined thermocline was evident although there was a fairly rapid decline in temperature from 15.1°C at 10 m to 11.6°C at 20-m depth. The limited amount of available information, therefore, indicates that Lower Arrow Lake thermally stratifies during the warm summer period (July and August), with the stratification breaking down in middle to late September.

Based on data collected by B.C. Research (1977) (Appendix B, Table B-1) and the B.C. Ministry of Environment (EQUIS Site 0200524) (Appendix B, Table B-2), dissolved oxygen concentrations varied little with depth, even during thermal stratification. This reflects the oligotrophic nature of the lake and the subsequent low biochemical oxygen demand in the deeper waters. The dissolved oxygen saturation levels during the fall of 1976, as presented by B.C. Research (1977), varied from 85% (surface) to 76% (bottom) saturation on 14 September and from 104% (surface) to 98% (16 m) on 25 November.

Surface saturation levels of total dissolved gas, dissolved oxygen, and dissolved nitrogen for Lower Arrow Lake have been summarized by Clark (1977) for the period 1972 to 1976 (Table 3.2). Surface total dissolved gas saturations varied between 94.3% (16 March 1976 at Syringa Park) to 108.6% (13 June 1975 in forebay and 14 June at Farquier), indicating that the lake does not become excessively supersaturated (i.e., 110% total dissolved gas saturation generally is considered by regulatory agencies to be the maximum level that will ensure survival and propagation of aquatic biota in shallow water - Weitkamp and Katz 1980). Dissolved nitrogen saturation varied betwen 93.4% and 110.7%. Surface dissolved oxygen levels generally were near or slightly above saturation, but high levels (up to 128.9%) were recorded periodically (Table 3.2). Spot sampling by the B.C. Ministry of Environment during the period January 1976 to August 1977 revealed even higher dissolved oxygen saturation levels (i.e., 132% and 139% saturation) (Table 3.3). The cause of the high dissolved oxygen saturations is not known, but may be due to high algal production in the surface waters during daylight hours.

Lower Arrow Lake is alkaline and is low in total ions, total dissolved solids, colour, turbidity, and nutrients (Table 3.3). Recent water chemistry data

Table 3.2. Dissolved gas saturation in Lower Arrow Lake. (Source: Clark 1977.)

Date	Percent Saturation		
	Total	Oxygen	Nitrogen
Hugh Keenleyside Forebay			
11 June 1972	106.4	106.4	106.6
22 June 1972	107.6	102.4	109.2
22 June 1972	105.1	96.6	107.6
25 July 1972	107.1	94.0	110.7
21 Aug. 1972	106.3	126.6	101.1
13 Sept. 1972	103.9	128.9	97.4
1 Mar. 1973	100.0	105.8	98.4
28 Mar. 1973	101.0	101.1	100.9
4 May 1973	103.5	103.2	103.6
22 Aug. 1973	105.5	99.0	107.3
17 June 1974	103.8	-	-
18 June 1974	106.9	-	-
3 July 1974	99.4	106.4	97.6
24 Oct. 1974	100.1	125.7	93.4
13 June 1975	108.6	111.7	108.0
25 July 1975	103.3	108.2	102.2
25 July 1975	101.7	104.0	101.2
16 Mar. 1976	99.9	-	-
Lower Arrow Lake at Syringa Park			
25 July 1975	103.9	101.0	104.8
16 Mar. 1976	94.3	-	-
Lower Arrow Lake at Farquier			
14 June 1975	108.6	110.5	108.4

Table 3.3. Water quality of Lower Arrow Lake, January 1976 to August 1977. (Source: B.C. Ministry of Environment 1979.)

Sampling Site		Lower Arrow Lake at Syringa EQUIS Site 0200524			
Parameter	Type of Value	Max.	Min.	Mean	No. of Values
Alkalinity, Total	mg/L	52	38	48	4
Arsenic, Total	mg/L	<0.005	< 0.005	< 0.005	2
Cadmium, Total	µg/L	<0.5	< 0.5	< 0.5	2
Carbon, Total Organic	mg/L	3	< 1	1.8	4
Chlorophyll a	µg/L	3.5	1.7	2.9	5
Colour, T.A.C.	Colour	1	1	1	2
True	Units	5	5	5	2
Copper, Total	mg/L	<0.001	< 0.001	< 0.001	4
Depth, Extinction	m	-	-	4.6	1
Hardness, Total	mg/L	60	56	57	4
Iron, Total	mg/L	0.1	< 0.1	0.1	4
Lead, Total	mg/L	<0.001	< 0.001	< 0.001	4
Manganese, Total	mg/L	<0.02	< 0.02	< 0.02	4
Nitrogen, Ammonia	mg/L	0.01	0.005	0.008	4
Nitrite + Nitrate	mg/L	0.14	0.1	0.12	4
Organic	mg/L	0.14	0.07	0.09	4
Total	mg/L	0.22	0.18	0.20	4
Oxygen, Dissolved	mg/L	11.0	8.6	9.8	4
Percent Saturation	%	139	132	136	2
pH		8.6	7.8	8.2	8
Phosphorus, Dissolved					
Orthophosphate	mg/L	< 0.003	<0.003	< 0.003	4
Total	mg/L	0.004	0.003	0.0035	4
Solids, Dissolved	mg/L	78	75	76	4
Suspended	mg/L	2	1	1.5	4
Turbidity	J.T.U.	0.7	0.3	0.5	4
Zinc, Total	mg/L	< 0.005	<0.005	< 0.005	4

collected by B.C. Ministry of Environment also indicated low levels of nutrients, turbidity, and metals throughout 1980 in Lower Arrow Lake near Syringa (EQUIS Site 0200524) (Appendix B, Table B-3). Water clarity generally is high; B.C. Research (1977) recorded Secchi depth values between 7 and 11 m during the fall of 1976.

3.1.1.4 Plankton/Macroinvertebrates

Lower Arrow Lake is low in biological productivity (i.e., oligotrophic) (B.C. Research 1977). Net primary production was 92.7 $mgC/m^2/d$ ranging from 1.5 $mgC/m^3/h$ (2 m) to 0.0097 $mgC/m^3/h$ (22 m). Chlorophyll **a** values ranged from 1.68 mg/m^3 (2 m) to 0.39 mg/m^3 (22 m).

A total of 28 algal taxa, representing five major groups (Classes) was recorded in Lower Arrow Lake (B.C. Research 1977). The Bacillariophyceae (diatoms) were most numerous, being represented by 23 species (82% of all taxa). The three most abundant species (of which all were diatoms) included **Asterionella formosa**, **Fragilaria crotonensis**, and **Synedra tabulata**.

The largest proportion of zooplankton collected from Upper and Lower Arrow lakes by B.C. Research (1977) were copepodid and nauplii stages of the Copepoda. Dominant zooplankton species included both Copepoda (**Cyclops bicuspidatus**, **Diaptomus leptopus**), and Cladocera (**Daphnia pulex**).

Annelids (segmented worms), Chironomini (midges), and **Pisidium** (clams) dominated the benthic invertebrate samples. **Pisidium** were restricted to deep (30 m), profundal areas of Lower Arrow Lake; no other macroinvertebrates were found in these samples. Annelids and chironomids were prevalent at shallower depths (5 and 15 m).

Larkin (1951) suggested that the introduction or planting of large invertebrates (Mysidacea: **Mysis relicta**; Amphipoda: **Pontoporeia**) into deep, oligotrophic lakes of British Columbia would provide a food source for juvenile trout. **Mysis relicta** were introduced into Arrow Lakes Reservoir in 1967 (B.C. Fish and Wildlife Branch N.D.), with further transplants into Upper Arrow Lake in the early 1970's (R. Lindsay, B.C. Fish and Wildlife Branch, pers. comm.); however, no studies have been conducted to document their abundance or effect on fish production in this system. Recent information, however, indicates that mysids

have formed a large population in Lower Arrow Lake. Large numbers of mysids collect on the filter screens at the BC Timber Ltd. and City of Castlegar water intake, located a short distance upstream of the Hugh Keenleyside Dam; this necessitates the back flushing of the screens at 8-hour intervals. The BC Timber Ltd. employees who service the screens indicated that fouling of the screens by mysids is most prevalent during the late fall and winter period (i.e., November to March).

Nocturnal vertical feeding movements of **Mysis relicta** have been reported by a number of authors (Beeton 1960; Gosho 1975; Morgan et al. 1978; Rieman and Bowler 1980). Prey items of **M. relicta** generally include **Daphnia** spp. and copepods. The thermocline (maximum rate of decrease of temperature with depth) may act as a barrier to the upward movement of **M. relicta** (Cooper and Goldman 1980). The effect of thermal stratification on mysid vertical movements in Lower Arrow Lake is unknown.

The extent to which rainbow trout and kokanee utilize mysids as a food source in Lower Arrow Lake has not been studied; however, in the North and South arms of Kootenay Lake, mysids contributed little to the diet of these species (A. Marten, B.C. Fish and Wildlife Branch, pers. comm.). This was attributed to the diurnal movement patterns of the mysids which result in their presence in the upper part of the water column only during a short period of time when the fish are actively feeding (i.e., late evening, early morning). The rest of the time, the mysids remain on or near the bottom in deep water and are essentially unavailable to the fish. Rieman and Bowler (1980) described a similar occurrence in Pend Oreille Lake where **Mysis relicta** contributed 7% of all food consumed by kokanee in 1977, and from 4 to 12% in 1978. A similar situation may well exist in the Arrow Lakes Reservoir.

3.1.2 FISHERIES RESOURCES

3.1.2.1 Habitat Description

There is little information describing the aquatic habitat of Lower Arrow Lake and its utilization by aquatic organisms. Typical cross-section profiles (B.C. Research 1977) suggest that the extent of shallow, nearshore areas is not great in Lower Arrow Lake. This, coupled with extensive annual fluctuations in

water level (up to 21 m, between elevations 441 and 420 m), severely limits the extent of littoral area in the lakes.

Utilization of Lower Arrow Lake by open water organisms may be high. The B.C. Fish and Wildlife Branch (unpubl. information) considers the Arrow Lakes Reservoir to be a much more productive environment for fish than the Columbia River below the Hugh Keenleyside Dam or the future Revelstoke Reservoir. In the Kootenay region, the Arrow Lakes Reservoir is considered by the B.C. Fish and Wildlife Branch to be second in importance to Kootenay Lake in terms of providing a recreational fishery.

The suitability of tributaries of Lower Arrow Lake for spawning, feeding, or rearing of sportfish (e.g., kokanee, rainbow trout, Dolly Varden) is not known. Generally, tributaries exhibit moderate to high gradients, with barriers impassable to migrating fish common in lower reaches. Isolated tributaries (Deer, Burton, Snow, and Caribou creeks) contain low gradient reaches accessible to Lower Arrow Lake fishes (F. Salekin, pers. comm.).

3.1.2.2 Fish Species Composition and Status

Little information is available on the fisheries resources of Lower Arrow Lake since impoundment in 1968. Although the tributary streams of Lower Arrow Lake have been investigated to determine enhancement potential for sportfish species, no detailed fisheries studies have been conducted within the main body of the reservoir (H. Andrusak, pers. comm.). In 1962 and 1963 (prior to impoundment of Arrow Lakes Reservoir), the B.C. Fish and Wildlife Branch studied the fish species composition of the Arrow Lakes and tributary streams. Although the status (i.e., relative abundance) of fish species likely has changed, the species composition still may be applicable (Table 3.4). A notable exception may be the walleye; since its introduction into Lake Roosevelt, this species has been documented as far upstream as the Columbia River at Castlegar. Walleye may have entered Lower Arrow Lake through the boat lock at the Hugh Keenleyside Dam. Unconfirmed reports of their presence in Lower Arrow Lake have been received.

Kokanee, rainbow trout, and Dolly Varden are the most sought after sportfish in Lower Arrow Lake. During the period 1974 to 1978, the importance

Table 3.4. Probable[a] fish species assemblage of Arrow Lakes Reservoir and tributary streams. This table is based on information provided in the pre-impoundment study (B.C. Fish and Game Branch 1965); creel surveys (Lindsay 1978; Lindsay and Seaton 1978); studies of Upper Arrow Lake tributaries (Steigenberger and Elson 1976; B.C. Ministry of Environment 1979; McPhail and Murray 1979); and the Murphy Creek Project fisheries studies (Ash et al. 1981; Ash and Luedke 1981).

Common Name	Scientific Name
Sport Fish[b]	
Mountain whitefish	**Prosopium williamsoni** (Girard)
Lake whitefish	**Coregonus clupeaformis** (Mitchill)
Eastern brook trout	**Salvelinus fontinalis** (Mitchill)
Yellowstone cutthroat trout	**Salmo clarkii lewisi** (Girard)
Rainbow trout	**Salmo gairdneri** Richardson
Dolly Varden[c]	**Salvelinus malma** (Walbaum)
Kokanee	**Oncorhynchus nerka** (Walbaum)
Burbot	**Lota lota** (Linnaeus)
White sturgeon	**Acipenser transmontanus** Richardson
Non-Sport Fish	
Pygmy whitefish	**Prosopium coulteri** (Eigenmann & Eigenmann)
Largescale sucker	**Catostomus macrocheilus** Girard
Longnose sucker	**Catostomus catostomus** (Forster)
Bridgelip sucker	**Catostomus columbianus** (Eigenmann & Eigenmann)
Northern squawfish	**Ptychocheilus oregonense** (Richardson)
Redside shiner	**Richardsonius balteatus** (Richardson)
Carp	**Cyprinus carpio** Linnaeus
Peamouth	**Mylocheilus caurinus** (Richardson)
Lake chub	**Couesius plumbeus** (Agassiz)
Leopard dace	**Rhinichthys falcatus** (Eigenmann & Eigenmann)
Longnose dace	**Rhinichthys cataractae** (Valenciennes)
Prickly sculpin	**Cottus asper** Richardson
Torrent sculpin	**Cottus rhotheus** (Smith)
Slimy sculpin	**Cottus cognatus** (Richardson)

[a] The reader should note that the list of species provided in this table has been inferred from pre-impoundment studies and studies in tributary streams. No detailed fisheries studies have been conducted in the reservoir and, as such, some species may have disappeared.

[b] Unconfirmed reports by local residents indicate that walleye (**Stizostedion vitreum** (Mitchill)) also may be present as a result of movement upstream through the boat lock at Keenleyside Dam.

[c] This species has recently been renamed the bull trout - **Salvelinus confluentus** (Suckley).

of kokanee as a sportfish increased substantially. In a 1971 creel census of Lower Arrow Lake, angling effort was divided equally between rainbow trout/Dolly Varden (angling for these species cannot be discriminated) and kokanee (Lindsay and Seaton 1978). A subsequent creel census in 1978 indicated only 14% of the total angling effort was directed at rainbow trout/Dolly Varden, while kokanee attracted 86% of the effort (Lindsay and Seaton 1978). The increase in effort towards kokanee likely reflects the reduced abundance of rainbow trout and Dolly Varden in the lake as a result of the loss of spawning and rearing habitat due to inundation by the Hugh Keenleyside Dam.

The importance of Lower Arrow Lake as a source of recruitment for the tailwater fishery below the Hugh Keenleyside Dam is not known. Evidence suggests kokanee below the Hugh Keenleyside Dam originate in Lower Arrow Lake (Ash et al. 1981; Ash and Luedke 1981). As well, part of the rainbow trout, Dolly Varden, lake whitefish, and mountain whitefish populations below the dam may originate in Lower Arrow Lake.

(a) Major Sport Species

i) Kokanee. Arrow Lakes Reservoir kokanee are derived from a natural population that was present prior to creation of the reservoir. The kokanee resident in Lower Arrow Lake generally are less than 30 cm in length as evidenced in the Deer Creek spawning run (Ash and Luedke 1981) and local angler catches (F. Salekin, pers. comm.). Infrequently, larger kokanee (length to 50 cm) are captured. Local residents (F. Salekin, pers. comm.) indicate larger kokanee are most often captured at the upper end of Lower Arrow Lake.

Kokanee are a common component of angler catches in Lower Arrow Lake. The B.C. Fish and Wildlife Branch (unpubl. data) estimated the total 1980 catch of kokanee as 10 000 fish. Kokanee escapement into tributary streams is estimated at 550 000 fish (H. Andrusak, pers. comm.). This escapement may be underestimated as nearshore spawning may occur.

Tributary streams utilized by kokanee for spawning and the extent of their utilization have not been identified. An estimated 1500 to 2000

kokanee spawners were present in Deer Creek on 2 September 1981 (estimate made from cursory survey conducted during the Murphy Creek fisheries study).

Kokanee are mainly limnetic plankton feeders, although food also may be derived from bottom organisms. In Pend Oreille Lake, kokanee appear to visually select for the largest and/or most abundant zooplankton prey items, with **Daphnia** being the preferred prey when present (Rieman and Bowler 1980). Mysids, although abundant in Pend Oreille Lake, did not contribute a major portion to the diet of kokanee, since they were unavailable to the kokanee during their active feeding periods.

Small kokanee may be an important forage fish for other sportfish species (i.e., rainbow trout and Dolly Varden). The B.C. Fish and Wildlife Branch recognizes the importance of kokanee as a forage fish in the production of trophy-sized rainbow trout in Lower Arrow Lake (H. Andrusak, pers. comm.).

ii) Rainbow Trout. Rainbow trout are the preferred sportfish of anglers in the West Kootenays. Although the rainbow trout in Lower Arrow Lake generally weigh between 0.5 and 1.8 kg, larger fish (up to 5.5 kg) are captured infrequently by anglers. As well, stream resident populations of rainbow trout are present in some low gradient reaches of tributary streams. The stream resident rainbow trout are typically stunted in growth (F. Salekin, pers. comm.).

The angler catch of rainbow trout in Lower Arrow Lake has decreased since creation of the Arrow Lakes Reservoir. Capture rates declined from 0.18 fish/rod hour in 1971 to 0.09 fish/rod hour in 1978. The B.C. Fish and Wildlife Branch (unpubl. preliminary data) have estimated the total catch of rainbow trout in 1978 to be 800 fish, while the spawning escapement to tributaries was estimated roughly at 1400 fish.

Crossman and Larkin (1959) noted that, in Paul Lake, B.C., redside shiners (or probably any small forage fish) were the major component of the rainbow trout diet. In the absence of this item, aquatic invertebrates became the major component of the diet. The diet of rainbow

trout in Lower Arrow Lake may be comprised of benthic invertebrates, zooplankton (possibly including mysids), and small fishes (kokanee may be important). However, the small size of the rainbow trout in angler catches suggests that zooplankton and benthic invertebrates may be the most important component of their diet.

iii) Dolly Varden. Dolly Varden are an important sportfish in the Arrow Lakes Reservoir. The majority of fish in the creel range from 1.4 to 3.6 kg; however, larger Dolly Varden (up to 9 kg) are captured occasionally. The B.C. Fish and Wildlife Branch has estimated that the total catch of Dolly Varden in Lower Arrow Lake in 1978 was approximately 500 fish; the spawning escapement of Dolly Varden presently is estimated at approximately 600 fish (H. Andrusak, pers. comm.).

McPhail and Murray (1979) indicate that growth of Dolly Varden in Upper Arrow Lake is rapid to age 5, at which time there is a clear growth asymptote corresponding to sexual maturity. They also noted that there is another increase in growth rate starting at about age 7+. This, they feel, probably reflects a size-related shift in diet.

Spawning by Dolly Varden in Mackenzie Creek, a tributary to Upper Arrow Lake, occurs in mid-September to late October (McPhail and Murray 1979). These authors indicate that the majority of Dolly Varden in Upper Arrow Lake rear for the first 2 or 3 years of life in tributary streams prior to entering the lake. The location and extent of spawning or rearing by this species in tributaries to Lower Arrow Lake has not been studied in detail.

Tag returns from B.C. Fish and Wildlife Branch studies indicate extensive movements of Dolly Varden in the Arrow Lakes Reservoir may occur (H. Andrusak, pers. comm.). A Dolly Varden, tagged in the Columbia River near Revelstoke, was recaptured immediately below the Hugh Keenleyside Dam. Coupled with the lack of evidence of Dolly Varden spawning in tributaries below the Hugh Keenleyside Dam, the downstream movement of Dolly Varden through the Hugh Keenleyside Dam may contribute substantially to the tailwater fishery of this species.

Adult Dolly Varden are mainly piscivorous. In Lower Arrow Lake, the diet of adult Dolly Varden likely includes kokanee and other small fish.

iv) Other Sport Species. Information regarding other sportfish in Lower Arrow Lake is limited. Prior to creation of the reservoir, the B.C. Fish and Game Branch (1965) documented the presence of mountain whitefish, lake whitefish, brook trout, cutthroat trout, burbot, and white sturgeon in Lower Arrow Lake. A similar composition of species may still be present today. As mentioned previously, walleye may now be present in Lower Arrow Lake as a result of upstream movement from Lake Roosevelt.

(b) Non-Sport Species

Available information regarding non-sport species in the Lower Arrow Lake drainage system is limited to a pre-impoundment survey conducted by the B.C. Fish and Game Branch (1965). Non-sport species that were reported are listed in Table 3.4.

3.2 COLUMBIA RIVER BELOW HUGH KEENLEYSIDE DAM

3.2.1 GENERAL LIMNOLOGY

3.2.1.1 Discharge

Monthly flows of the Columbia River at Birchbank (near Murphy Creek) before (1914-67) and after (since 1968) regulation are presented in Figures 3.3 and 3.4. Regulation has modified seasonal fluctuations so that summer peaks have been reduced and winter lows have been increased. Peak discharge occurs in winter (about 3400 m^3/s) and subsequently declines to a low in March-April (about 1400 m^3/s). Discharge increases through spring and is relatively stable from May to August (about 2100 to 2800 m^3/s). Flows decrease and reach a low in the fall (about 1400 m^3/s); subsequently, they increase during winter.

3.2.1.2 Water Temperature

Post-regulated maximum and minimum water temperatures for Trail, B.C. are presented in Figure 3.5. Water temperatures are lowest in January-

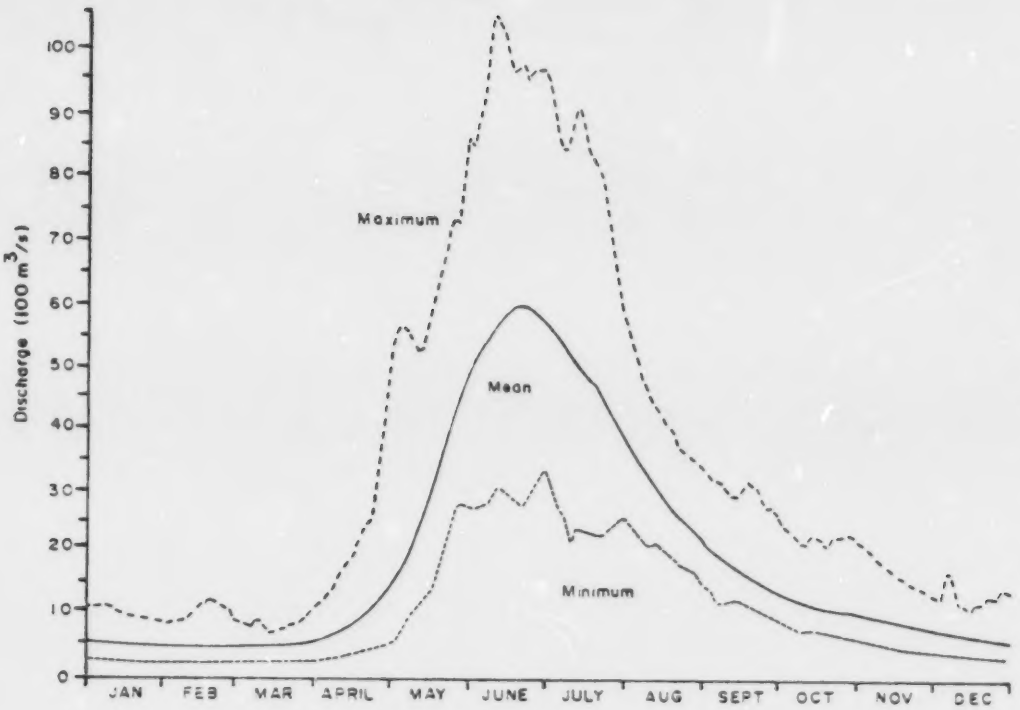


Figure 3.3. Natural discharge (pre-regulation) of the Columbia River, 1914 to 1967. (Source: B.C. Hydro 1981.)

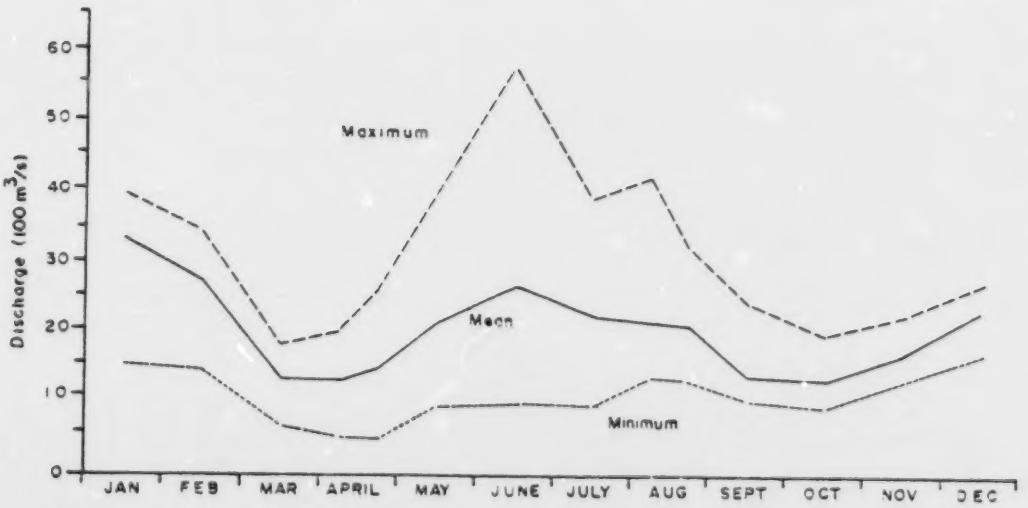


Figure 3.4. Monthly flows of the regulated Columbia River at Birchbank based on 1940 to 1975 computer simulation of regulated conditions (Regime 1). (Source: B.C. Hydro 1981.)

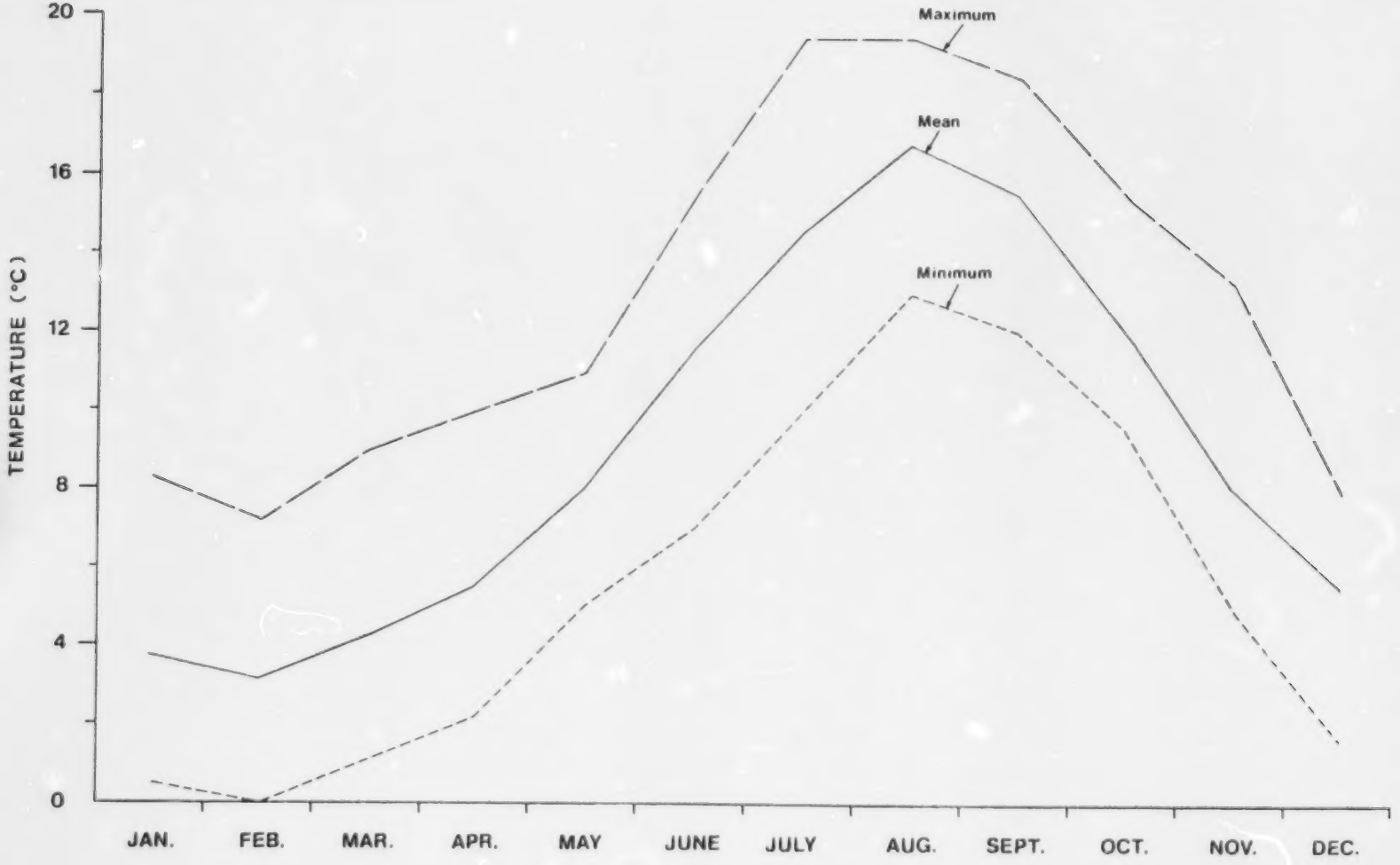


Figure 3.5. Temperatures recorded in the Columbia River at Trail, 1969 to 1976. (Source: B.C. Hydro 1981; revised 1983.)

February (0.5° to 4°C) and gradually increase to maximum levels in July-August (13° to 19.5°C). In most years, ice cover does not form on the Columbia River between the Hugh Keenleyside Dam and Trail.

3.2.1.3 Dissolved Gas Supersaturation

A detailed discussion of dissolved gas supersaturation in the Columbia River below the Hugh Keenleyside Dam was presented in the Murphy Creek Project fisheries report (Ash et al. 1981); however, due to the importance of this topic to the proposed Keenleyside Powerplant Project and the important fish stocks in the Columbia River, the relevant information presented in Ash et al. (1981) has been repeated in the following discussion.

The Columbia River below the Hugh Keenleyside Dam has been identified as having the highest total dissolved gas (TDG) concentrations of the 35 major rivers or lakes examined in British Columbia (Clark 1977). A total dissolved gas concentration of 144% saturation was recorded by the B.C. Pollution Control Branch on 17 August 1976.

The TDG saturations were highest in the section of the Columbia River between the Hugh Keenleyside Dam and the Kootenay River. In the downstream section of the Columbia River, the TDG values were lower (maximum reported was 136% saturation - Clark 1977) as a result of dilution by the Kootenay River water which contained lower TDG levels (maximum of 132% saturation), and as a result of equilibrium with the atmosphere.

High concentrations of dissolved gases, however, can be maintained for a substantial distance downstream. High levels at the Grand Coulee Dam and throughout Lake Roosevelt in Washington have been attributed to supersaturation occurring at upstream dams on the Columbia River in Canada (Seattle Marine Laboratories 1972). The total dissolved nitrogen levels in water entering Lake Roosevelt (above 120% saturation from April through August) decreased only slightly (2 or 3% saturation) as the water moved the 225 km through the lake to the Grand Coulee Dam (Seattle Marine Laboratories 1974).

In an attempt to determine the major factors affecting the concentrations of dissolved gases in the Columbia River, saturation levels reported by Clark (1977) were plotted against discharge, hydraulic head at the Hugh

Keenleyside Dam, and month (Table 3.5; Figure 3.6). No clear relationships were shown although a slight positive correlation was noted between TDG saturation and hydraulic head ($r^2 = 0.38$). It was evident that high TDG saturation levels occurred when the sluiceway, rather than the low level ports, was used to discharge water. Statistical analyses (Student's t-test) showed that the mean TDG levels during periods when only the sluiceway was discharging ($\bar{x} = 128.9\%$; $n = 22$) were significantly higher ($p < 0.01$) than the mean concentration during periods when only the low level ports were discharging ($\bar{x} = 102.6\%$; $n = 7$).

The cause of supersaturation below the Hugh Keenleyside Dam appears to be related primarily to the mode of discharge from the dam (i.e., sluiceway vs. low level ports) (B.C. Ministry of Environment 1979). As the water passes over the sluiceway, air is entrained in the water as it plunges into the deep pool and energy dissipator located below the sluiceway. As the water is carried to considerable depth in the plunge pool, the air entrained is dissolved in the water under the hydrostatic pressure created by the water column above it. As the water returns to the surface, the pressure is reduced and the water becomes supersaturated. In contrast, water that is discharged through the low level ports does not become excessively supersaturated because the ports are always submerged, so there is no opportunity for air to become entrained in the water. Since the low level ports are normally operated only when the head differential between the forebay and the tailwater is less than 9.1 m (J. Muralt, B.C. Hydro, pers. comm.), this likely explains the positive correlation between available head and TDG saturations described above (i.e., the sluiceway is required for discharge at the higher heads).

The B.C. Ministry of Environment (1979) notes that the considerable variation in TDG levels at similar discharge through the sluiceway suggests that other factors, such as water temperature, reservoir elevation, tailwater elevation and the differential head, also may be important; however, they could not identify any apparent patterns.

High levels of total dissolved gas have long been known to affect aquatic animals living in fresh or salt water. The resulting condition in fish or aquatic invertebrates subjected to high TDG levels is called gas bubble disease; the

Table 3.5. Total dissolved gas (TDG) concentrations in the Columbia River below the Hugh Keenleyside Dam. (Source: Ash et al. 1981.)

Date	TDG[a] % Sat.	Discharge[b] (m^3/s)	Hydraulic Head (m)[b]	No. of Ports Open[b]	No. of Sluiceway Gates Open[b]
Discharge Through Ports Only					
25 Jan. 1973	99.3	1418	6.21	3	
1 Mar. 1973	100.0	213	5.36	3	
28 Mar. 1973	100.8	142	6.25	2	
4 May 1973	104.4	273	6.25	4	
13 June 1973	105.7	555	7.40	3	
22 Aug. 1973	104.3	1994	1.66	8	
18 Mar. 1976	104.0	915	9.16	3	
Discharge Through Ports and Over Sluiceway					
6 Jan. 1973	111.8	1920	8.85	2	4
16 Mar. 1976	103.7	885	9.19	1	4
17 Mar. 1976	121.0	967	8.96	3	4
Discharge Over Sluiceway Only					
11 June 1972	132.0	2694	10.91		4
22 June 1972	135.8	4357	11.81		4
22 June 1972	135.1	4357	11.81		4
25 July 1972	131.6	3005	17.67		4
25 July 1972	133.8	3005	17.67		4
21 Aug. 1972	128.7	1752	19.94		4
13 Sept. 1972	115.4	668	22.32		4
17 June 1974	113.2	146	13.16		1
18 June 1974	110.3	148	13.62		1
3 July 1974	100.6	1427	17.40		4
24 Oct. 1974	115.8	861	16.36		4
13 June 1975	129.7	148	11.74		1
15 June 1975	132.8	145	12.60		1
16 June 1975	132.8	146	13.07		1
25 July 1975	134.1	147	15.94		1
17 June 1976	131.0	857	14.05		4
8 July 1976	138.4	864	19.05		4
22 July 1976	133.1	2287	18.48		4
7 Aug. 1976	121.8	3177	17.86		4
17 Aug. 1976	144.0	3757	16.87		4
19 Aug. 1976	143.0	3587	17.55		4
20 Aug. 1976	142.5	3041	17.80		4

[a]from Clark (1977).

[b]from B.C. Hydro (unpubl. data).

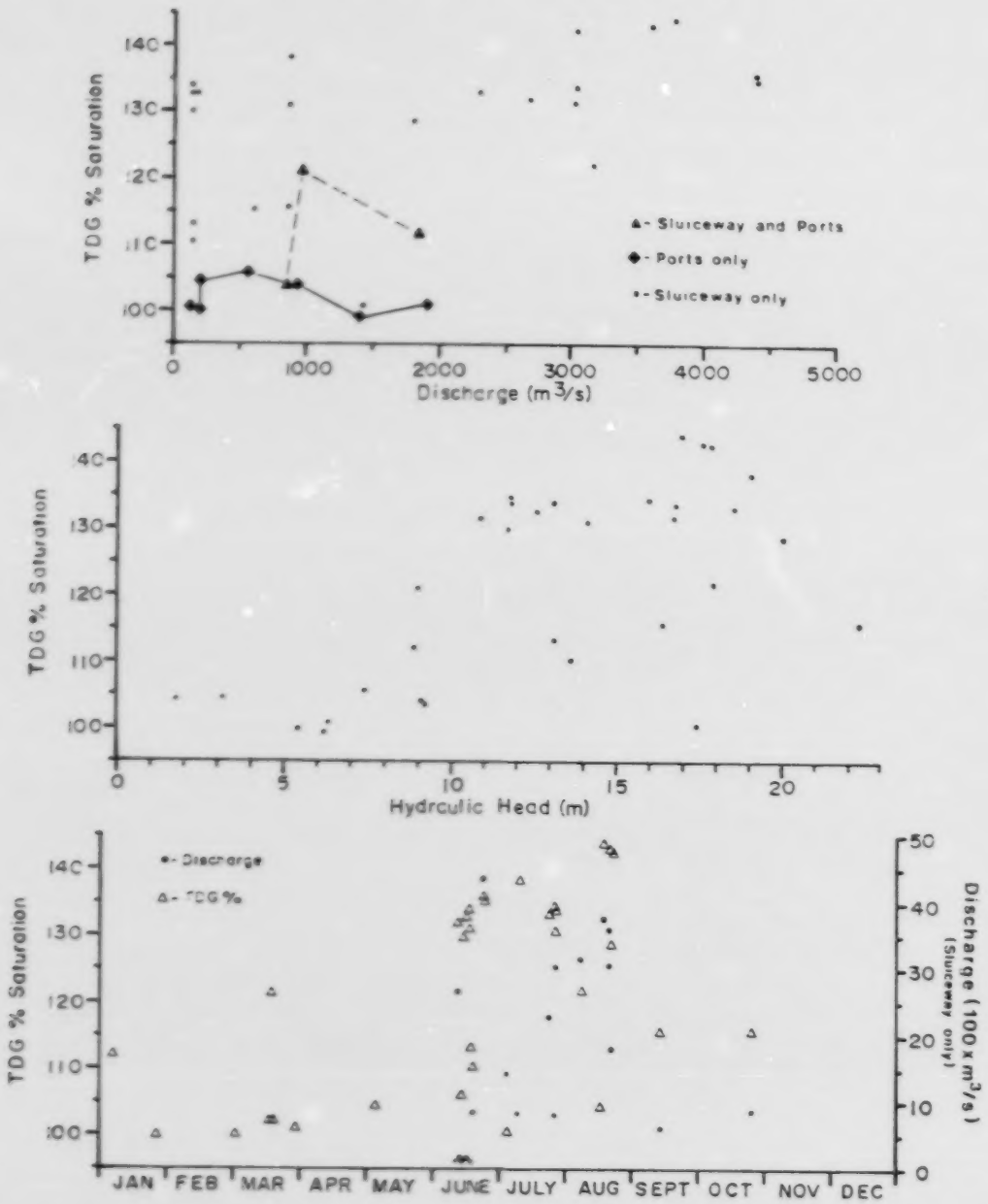


Figure 3.6. Total dissolved gas concentrations (TDG) in the Columbia River below the Hugh Keenleyside Dam (1972 to 1976) plotted against discharge, hydraulic head of the dam, and month (from Clark 1977; B.C. Hydro, unpubl. data) (original of this figure presented in Ash et al. 1981).

available literature on gas bubble disease has been reviewed in detail by Weitkamp and Katz (1980).

The major external signs of the disease in fish include:

- gas bubbles on fins, head, roof of mouth, and along the lateral line;
- protruding eyes (exopthalmia);
- hemorrhage; and
- embolism, particularly in the blood vessels of the gills.

Other characteristics of gas bubble disease that have been reported include loss of equilibrium, behavioural changes, and reduced growth (Weitkamp and Katz 1980). In extreme cases of gas bubble disease, the cause of death generally has been attributed to anoxia resulting from stasis of the blood, either through emboli in the heart or in the gill arterioles (Weitkamp and Katz 1980). Other sublethal effects such as blindness, stress, and decreased lateral line sensitivity can lead to death from other causes such as predation or disease.

According to the literature, a wide range of TDG saturation can cause high mortality in test animals (Table 3.6). Some investigators report coarse fish species (e.g., northern squawfish) as being more resistant than salmonids when stressed with supersaturation (Blahm 1974 in Bentley et al. 1976), while other researchers have indicated coarse fish to be of equal or lower tolerance (Meekin and Turner 1974). Variation within a species also may be high. For example, Fickeisen and Montgomery (1978) recorded time to lethal exposure for 50% mortality (LE50) for cutthroat trout held at 128% TDG saturation as 12 hours, while May (1973) reported the LE50 for this species at 125% to 131% TDG, as being 53 hours. Depth of testing, among other variables, can result in LE50 variation. Ebel et al. (1975) reported that, when confined to a depth less than 0.5 m, juvenile steelhead trout had significant mortality (i.e., 50%) at 115% saturation after 20 days. Also, if the saturation level exceeds 120%, substantial mortality (i.e., 50%) would occur after 20 days' exposure even if the fish were allowed to sound to greater depths (i.e., tested to 2.5 m) to obtain hydrostatic compensation (Dawley et al. 1975 in Ebel et al. 1975). Weitkamp and Katz (1973) reported that fish in waters of 123% to 143% nitrogen saturation would have to remain below a depth of 2.5 m in order to remain free of gas bubble disease symptoms. Figure 3.7 gives a pictorial representation of the relationship

Table 3.6. Summary of total dissolved gas (TDG) supersaturation bioassays compiled from literature sources. (LE50 is time to lethal exposure for 50% of individuals tested.)

Species	Supersaturation Level	Lethal Exposure Time	Reference
Sockeye salmon	116.7% TDG	LE50 in 96 h	Nebeker and Brett (1976)
Rainbow trout	130% N_2 for 16 h/d	LE50 in 16-70 h	Blahm et al. (1973) cited in Weitkamp and Katz (1980)
Cutthroat trout	116% TDG	LE50 in 89 h	Fickeisen and Montgomery (1978)
	120% TDG	LE50 in 34 h	
	124% TDG	LE50 in 17 h	
	128% TDG	LE50 in 12 h	
	110-127% TDG	LE50 in 14 d	May (1973)
	125-131% TDG	LE50 in 2.2 d	
Mountain whitefish	116% TDG	LE50 in 48 h	Fickeisen and Montgomery (1978)
	120% TDG	LE50 in 50 h	
	124% TDG	LE50 in 14 h	
	128% TDG	LE50 in 12 h	
	116-127% TDG	LE50 in 12 d	May (1973)
Northern squawfish	120% TDG	LE50 in 9.7 d	Bentley et al. (1976)
	126% TDG	LE50 in 20 h	
Largescale sucker	120% TDG	LE50 in 103 h	Fickeisen and Montgomery (1978)
	124% TDG	LE50 in 67 h	
	128% TDG	LE50 in 34 h	
Stoneflies	125% TDG	LE50 not achieved	Nebeker et al. (1976)
Daphnia sp. non-egg-carrying adults	120% TDG	LE50 in 91 h	Nebeker et al. (1976)
	130% TDG	LE50 in 65 h	
	140% TDG	LE50 in 71 h	

(Source: Ash et al. 1981)

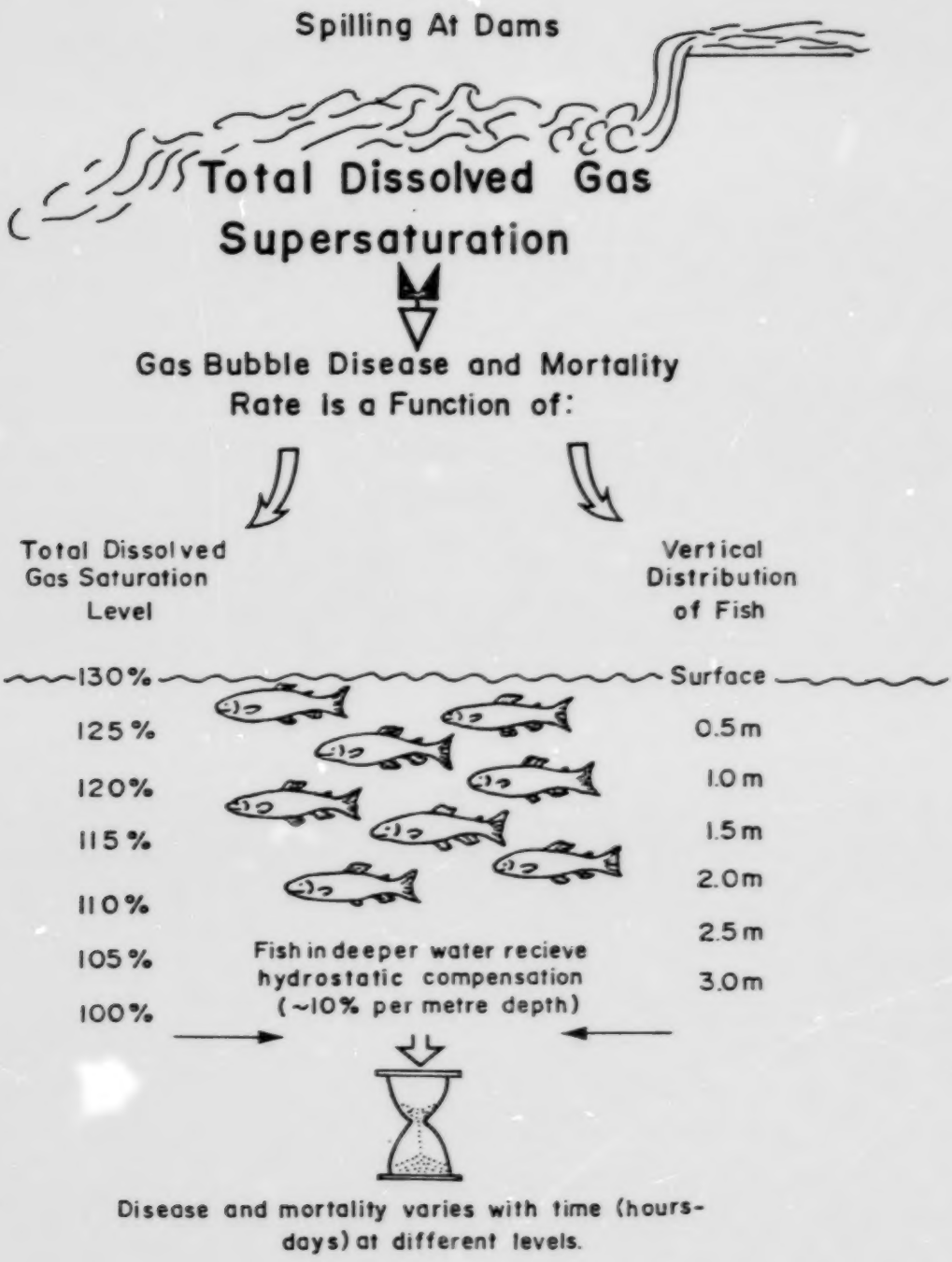


Figure 3.7. Generalized representation of cause and effect relationship in gas supersaturation-gas bubble disease-fish mortality (adapted from Ebel et al. 1975).

between surface saturation levels, exposure time, depth distribution of fish, and hydrostatic compensation.

A number of studies have indicated that intermittent exposure to high TDG levels will allow fish to tolerate supersaturation for longer periods, indicating that some recovery occurs during short periods of reduced supersaturation (Weitkamp and Katz 1980). This suggests that fish are able to withstand short periods of high TDG levels in shallow water if they sound to a greater depth for recovery. However, there is conflicting evidence regarding the ability of fish to detect and avoid high TDG saturations. Weitkamp and Katz (1980) indicate that it had generally been accepted that fish are not able to detect supersaturation and avoid it; however, they indicated that recent studies suggest that some species such as chinook salmon, coho samon, steelhead, and northern squawfish may be able to detect and avoid supersaturation. Stevens et al. (1980) have provided further evidence that chinook, coho, and sockeye salmon smolts and rainbow trout can detect supersaturation; however, they noted that steelhead did not avoid the supersaturated waters in their circular test tanks. They suggested that territorial behaviour reduced the avoidance by steelhead and, to a lesser extent, by rainbow trout.

The extent to which high total dissolved gas levels affect the fish populations in the Columbia River below the Hugh Keenleyside Dam is unknown. Based on published lethal levels, the total dissolved gas concentrations in the Columbia River (i.e., reported by Clark 1977; Table 3.5) would cause significant mortality (i.e., at least 50%) within approximately 12 hours for salmonids and whitefish held near the surface, and within 34 hours for suckers, during most of the summer months. It is likely, however, that the fish in the Columbia River usually can avoid gas supersaturation problems by remaining in deep water throughout most of the day.

Clark (1977) reported that of the 40 adult fish collected between the Hugh Keenleyside Dam and the Castlegar Ferry during July and August 1976 (TDG concentrations were approximately 140% saturation), only one exhibited minor symptoms of gas bubble disease. This information, in conjunction with the existence of a viable sportfishery in this section of the Columbia River, suggests that most of the fish species present generally can avoid gas bubble disease

during periods of high TDG levels by remaining in deep water for sufficient periods of time each day. However, during the winter of 1980-81, there was a dramatic unexplained decrease in the abundance of kokanee in the Columbia River (Ash et al. 1981; B.C. Fish and Wildlife Branch 1981). It is possible that high TDG levels during the winter may have been responsible for the decline; however, no data are available to support or reject this hypothesis.

Although high TDG concentrations can be detrimental to fish populations, supersaturated water can be beneficial in lessening the effects of high organic matter entering the Columbia River from municipal and industrial sources in the study area by maintaining elevated dissolved oxygen levels. Organic effluents from the following sewage treatment plants, all of which receive secondary treatment, enter the Columbia River within the study area (R. Crozier, pers. comm.):

Locale	Pollution Control Permit	Maximum Permitted Discharge (litres per day)
BC Timber	P.E. 1273	113 625
City of Castlegar Lagoons	P.E. 80	2 727 000
City of Castlegar	P.E. 4008	3 272 400
Selkirk College	P.E. 141	136 350

IEC (1981) indicated that no appreciable oxygen sag (i.e., reduction in dissolved oxygen concentrations due to oxidation of materials in the water) occurs in the section in the Columbia River between the BC Timber Ltd. effluent outfall and Birchbank.

3.2.1.4 Nutrients

Water quality of the Columbia River is monitored by the B.C. Ministry of Environment at designated EQUIS (Environmental Quality Information System) sampling locations. Continuous, short-term monitoring is being conducted by the B.C. Waste Management Branch (Nelson) at effluent sites downstream from the Hugh Keenleyside Dam (R. Crozier, pers. comm.).

Beak (1980) and IEC (1981) present water quality summary data for nitrogen and phosphorus at sites along the Columbia River downstream from the

Hugh Keenleyside Dam. Ash et al. (1981) briefly summarize these data. None of these studies relate nutrient levels to biological productivity in the river system.

Beak (1980) reported that the most significant increase in total Kjeldahl nitrogen (TKN) and total phosphorus (TP) occurred near the CanCel (now BC Timber Ltd.) effluent outfall (Tables 3.7 and 3.8). Nutrient levels at sites downstream from the effluent were low and comparable to upstream control sites. Thus, the effluent constituents were rapidly diluted.

Water quality data summarized by IEC (1981) were based on collections and analysis of water samples at three sites along the Columbia River (downstream of the Hugh Keenleyside Dam, downstream of the Brilliant Dam, and at Birchbank). All data presented by IEC (1981) are averages which have been calculated from a minimum of 30 values. The ranges in average concentration among the three sites for the various nitrogen components were as follows: ammonia N—0.007 to 0.009 mg/L; nitrite/nitrate N—0.055 to 0.124 mg/L; organic N—0.059 to 0.098 mg/L; total Kjeldahl N—0.068 to 0.105 mg/L; and total N—0.160 to 0.192 mg/L. The ranges in average concentration of orthophosphate and total phosphorus (as P) were reported as 0.003 to 0.006 mg/L and 0.007 to 0.013 mg/L, respectively.

With the exception of point source effluents (e.g., BC Timber Ltd.), nutrient levels (phosphorus and nitrogen) in the Columbia River within the study area are low.

3.2.1.5 Plankton/Macroinvertebrates

Although natural populations of zooplankton exist in large rivers, plankton generally originate from lakes and occur in rivers at lake outflows (Hynes 1970). **Mysis relicta** which are present in the upper section of the Columbia River within the study area, originate in Arrow Lake and are transported through the low level ports or the sluiceway of the Hugh Keenleyside Dam. Ash et al. (1981) reported nighttime collections of **M. relicta** downstream from the dam during the summer and fall. The relative abundance of mysids tended to decrease with increasing distance from the dam (Table 3.9) (Ash et al. 1981). Mysids constitute an important food source for fish (kokanee, rainbow trout) in the Columbia River, with heaviest utilization near the Hugh Keenleyside Dam

Table 3.7. Water quality analyses, Columbia and Kootenay rivers, 11 June 1980 (Columbia River Flow = 161.6 m^3/s; Kootenay River Flow = 872.2 m^3/s). (Source: adapted from Beak 1980.)

Parameter†	Station*												
	1		2		3		4		5		Kootenay River	6	
	N	S	N	S	N	S	N	S	E	W		E	W
pH (pH Units)	7.5	7.6	7.6	7.3	7.6	7.3	7.3	7.3	7.2	7.2	7.9	7.9	7.6
Total Alkalinity	54	54	53	54	55	55	46	58	51	48	53	53	52
True Colour (APHA Units)	5	5	5	30	5	20	20	40	30	30	5	5	10
Turbidity (JTU)	0.90	0.55	0.50	1.10	0.95	0.80	0.95	1.00	3.00	3.00	0.85	0.90	0.95
Suspended Solids	8	4	2	6	4	5	3	5	4	4	4	4	6
Conductivity (µS/cm)	129	128	127	154	123	146	125	157	140	135	125	125	121
Tannin/Lignin	0.3	0.2	0.2	2.7	0.4	2.0	1.9	3.5	2.3	2.5	0.2	0.3	0.5
Total Kjeldahl Nitrogen	0.40	0.45	0.61	1.10	0.29	0.48	0.35	0.59	0.60	0.49	0.41	0.32	0.42
Total Phosphate	0.007	0.007	0.006	0.015	0.005	0.004	0.009	0.006	0.007	0.007	0.006	0.005	0.010
Chloride	1.4	0.7	0.6	7.6	1.0	2.6	2.0	4.5	3.6	4.0	1.1	1.1	1.3
Sodium	1.8	1.0	1.2	5.6	1.3	4.3	3.7	6.5	4.4	4.5	1.4	1.5	1.8
BOD	5	4	4	8	3	5	4	6	5	4	2	2	3
Dissolved Oxygen	13.4	13.4	13.5	12.3	13.3	12.7	11.7	11.7	11.8	11.8	12.3	12.3	12.1
% Saturation DO	135	134	135	124	136	130	117	124	118	118	121	121	120
Water Temperature (°C)	13.5	13.0	13.5	13.5	14.0	14.0	13.0	15.5	13.0	13.0	12.0	12.0	12.5
Depth (m)	9.7	16.4	13.0	9.1	11.8	11.8	9.7	3.6	4.2	6.2	4.8	8.0	5.0
Secchi Transparency (m)	4.5	3.9	3.5	1.1	2.9	1.7	1.7	1.2	1.2	1.5	2.4	1.7	1.7

* N = North side; S = South side; E = East side; W = West side; Stations 1-6 situated in the Columbia River.

† All values in mg/L unless otherwise stated.

◆ B C Timber Ltd. effluent diffuser.

Table 3.8. Water quality analyses, Columbia and Kootenay rivers, 28 August 1980 (Columbia River Flow = 1274.3 m^3/s; Kootenay River Flow = 489.9 m^3/s). (Source: adapted from Beak 1980.)

Parameter†	Station*												
	1		2		3		4		5		Kootenay River	6	
	N	S	N	S	N	S	N	S	E	W		E	W
pH (pH Units)	7.7	7.7	7.7	7.6	7.7	7.6	7.7	7.6	7.7	7.6	8.1	7.9	7.8
Total Alkalinity	43	43	42	42	42	42	42	43	43	42	57	48	45
True Colour (APHA Units)	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Turbidity (JTU)	0.50	0.50	0.40	0.50	0.35	0.55	0.50	0.65	0.45	0.50	0.70	0.60	0.55
Suspended Solids	<1	1	<1	1	<1	<1	1	<1	<1	<1	2	<1	<1
Conductivity (µS/cm)	100	100	100	105	100	104	100	104	101	102	135	114	109
Tannin/Lignin	0.1	0.1	0.1	0.4	0.1	0.4	0.1	0.3	0.2	0.3	0.1	0.2	0.2
Total Kjeldahl Nitrogen	<0.05	0.06	<0.05	0.06	0.09	0.07	<0.05	<0.05	0.06	<0.05	0.08	0.06	0.07
Total Phosphate	0.004	0.005	0.003	0.007	0.009	0.009	0.005	0.010	0.006	0.007	0.012	0.008	0.007
Chloride	0.2	0.2	0.2	1.3	0.2	1.1	0.2	1.0	0.5	0.7	0.7	0.7	0.8
Sodium	0.5	0.4	0.5	1.1	0.5	1.0	0.5	0.9	0.7	0.8	1.2	0.9	0.9
BOD	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Dissolved Oxygen	12.7	12.4	12.8	12.4	12.5	12.4	12.7	12.4	11.7	12.2	11.0	11.1	11.7
% Saturation DO	130	126	130	128	128	129	130	129	120	125	119	116	121
Water Temperature (°C)	14.0	13.5	13.5	14.5	14.0	14.0	14.0	14.0	14.0	14.0	16.5	15.0	15.0
Depth (m)	13.0	16.5	19.0	12.0	16.0	13.5	10.0	5.0	6.0	4.5	5.5	6.0	6.0
Secchi Transparency (m)	5.0	5.0	4.0	4.5	4.0	3.0	4.0	4.0	4.0	4.0	3.5	3.5	3.5

* N = North side; S = South side; E = East side; W = West side; Stations 1-6 situated in the Columbia River.

† All values in mg/L unless otherwise stated.

◆ B C Timber Ltd. effluent diffuser.

Table 3.9. **Mysis relicta** densities in the Columbia River below the Hugh Keenleyside Dam, 1980 and 1981. (Source: Ash et al. 1981.)

Date	Location (km) Upstream of International Border	Time	Density (No./m^2)
1980			
7 May	51.2	2300	0
	55.5	2315	0
	56.0	2330	0
12 July	54.3	0154	118.8
	49.2	0249	25.0
	54.3	0343	40.6
11-12 Sept.	55.5	2300	150.0
	53.8	2320	108.3
	52.7	2400	25.0
	52.4	0030	66.7
	49.2	0117	13.9
1981			
6 Feb.	52.4	2130	5.6

(Lindsay 1976; Ash et al. 1981). Fish feeding activities may influence the distribution of mysids in the river; however, the abundance and distribution of mysids and other zooplankton in the Columbia River has not been studied in detail.

Existing data on benthic invertebrates inhabiting the Columbia River focus on the biota as pollution indicators (Beak 1980) or as target species in toxicity studies (B.C. Ministry of Environment 1979). Beak (1980) showed that there was a high proportion of pollution tolerant organisms near the discharge of the pulp mill near Castlegar, but that the proportion of these organisms gradually declined with increasing distance from the point source.

B.C. Ministry of Environment (1979) monitored metal accumulation of cadmium, lead, and zinc by invertebrates that were collected in the Columbia River at Birchbank and at sites downstream from the effluent at Cominco Ltd. Invertebrate metal accumulation was lower at Birchbank than at the other stations which were located below the Cominco Ltd. effluent. Although the invertebrates were not identified in detail, the caddisfly **Hydropsyche** sp. appeared to be resistant to elevated levels of cadmium, lead, and zinc.

3.2.2 FISHERIES RESOURCES

The reaches of the Columbia River between Castlegar and the Hugh Keenleyside Dam are extensively utilized by a variety of sport and non-sport fish species (Ash et al. 1981). A diversity of habitat types, and a supply of food organisms from Arrow Lakes Reservoir, provide conditions conducive to the growth of many life stages of these fishes. The abundance of sportfish (primarily rainbow trout, Dolly Varden, kokanee, and burbot) in the Columbia River above Castlegar is reflected in a large amount of angling effort (B.C. Fish and Wildlife Branch 1981). Due to the proximity of this section of the Columbia River to the project site (i.e., Hugh Keenleyside Dam) and potential for impact by the project, a general inventory of the aquatic resources is given on the following pages. For a more detailed discussion of the fish resources in this river section, and in the Columbia River to the U.S.A. border, refer to the Murphy Creek Project fisheries studies (Ash et al. 1981; Ash and Luedke 1981).

3.2.2.1 Habitat Description

The Columbia River between Castlegar and the Hugh Keenleyside Dam exhibits a low gradient averaging 0.18 m/km. The resulting flow character generally is placid or swirling; however, rolling and broken flows extend up to 300 m below the outlets (i.e., sluiceway, low level ports) of the Hugh Keenleyside Dam. The Columbia River between Castlegar and the dam can be differentiated into the following two reaches, based primarily on water quality (Ash et al. 1981).

(a) Reach A

This reach extends 3.2 km below the Hugh Keenleyside Dam to the BC Timber Ltd. effluent diffuser. Water quality in this section is considered good, with the exception of periodically high levels of total dissolved gases. Banks in this reach are generally repose, up to 10 m in height, and composed of glacial till. A bedrock outcrop constitutes the north bank immediately below the Hugh Keenleyside Dam. Inshore areas drop off rapidly in this reach, with shallow areas occurring only infrequently. Boulder and cobble substrates have greatest distribution in inshore areas, although isolated areas of sand and gravels are present. Silts covered visible substrates (i.e., inshore areas) throughout most of this reach; however, inshore areas associated with the turbulent waters below the outlets of the dam experience a lesser degree of siltation.

The extensive fish utilization of Reach A can be partially attributed to the high rearing potential of the area. Low current velocities and the input of food organisms (i.e., zooplankton, including mysids) from Lower Arrow Lake contribute to the high rearing potential for most sportfish species.

The salmonid spawning potential in Reach A is limited by steep bank types, siltation, scarcity of suitable substrates, large water level fluctuations, and high dissolved gas concentrations. Isolated areas may provide suitable spawning habitat for salmonid species but the extent to which these areas are utilized is not known.

(b) Reach B

This reach extends from the BC Timber Ltd. effluent diffuser (Km 53.0) to the Castlegar Ferry (Km 49.0). Water quality in Reach B is reduced by effluent discharged from the BC Timber Ltd. pulp mill (Beak 1980; B.C. Ministry of Environment 1979). Bank form in Reach B varies between flat and steep. The irregular shoreline displays a large percentage of fine materials (i.e., sand-silt and organic debris); consequently, expanses of shallow areas with sand-silt substrate are common in inshore areas, especially in bights produced by the irregular shoreline. Aquatic vegetation is abundant in many such areas. Isolated sand and gravel deposition bars also are present in Reach B (e.g., left bank Km 53-52.5).

The potential utilization for spawning of isolated areas of gravel deposition is limited by siltation and water level fluctuations. The extent of salmonid spawning in Reach B is not known. Coarse and forage fish species may utilize shallow vegetated areas for spawning. Local residents reported observing carp spawning activity in such areas.

Sampling results in 1980 and 1981 (Ash et al. 1981) suggest Reach B has a high rearing potential for many of the resident fish species. A number of factors appear to contribute to the high rearing potential of Reach B; these include low water velocity, and extensive shallow areas with abundant aquatic vegetation.

3.2.2.2 Fish Species Composition and Status

The utilization of the Columbia River between the Hugh Keenleyside Dam and Castlegar by a variety of fish species is substantial (Table 3.10). Over 100 000 fish, comprised of 18 species, were captured or observed during sampling of this river section in 1980 and 1981 (Ash et al. 1981; Ash and Luedke 1981). The majority of these, however, were forage or coarse fish species (e.g., redside shiner, suckers).

The high degree of utilization may be attributed to a combination of factors. Firstly, the large number of small fish (e.g., young-of-the-year and yearling sport, forage, and coarse fish) present may reflect the quality of rearing habitat available (see previous section). Secondly, the Hugh Keenleyside Dam provides an essentially unilateral input of nutrients, food organisms, and fish

Table 3.10. Fish species encountered in the Columbia River between Castlegar and the Hugh Keenleyside Dam, 1980 and 1981. (Source: Ash et al. 1981; Ash and Luedke 1981.)

Common Name	Species Code	Scientific Name
Kokanee	(K)	**Oncorhynchus nerka** (Walbaum)
Rainbow trout	(RT)	**Salmo gairdneri** Richardson
Dolly Varden	(DV)	**Salvelinus malma** (Walbaum)
Walleye	(YW)	**Stizostedion vitreum vitreum** (Mitchill)
Burbot	(LING)	**Lota lota** (Linnaeus)
Mountain whitefish	(MW)	**Prosopium williamsoni** (Girard)
Lake whitefish	(LW)	**Coregonus clupeaformis** (Mitchill)
White sturgeon	(WST)	**Acipenser transmontanus** Richardson
Longnose sucker	(LNS)	**Catostomus catostomus** (Forster)
Largescale sucker	(LSS)	**Catostomus macrocheilus** Girard
Bridgelip sucker	(BLS)	**Catostomus columbianus** (Eigenmann & Eigenmann)
Carp	(Carp)	**Cyprinus carpio** Linnaeus
Redside shiner	(RSS)	**Richardsonius balteatus** (Richardson)
Northern squawfish	(NSF)	**Ptychocheilus oregonensis** (Richardson)
Peamouth	(PM)	**Mylocheilus caurinus** (Richardson)
Longnose dace	(LND)	**Rhinichthys cataractae** (Valenciennes)
Prickly sculpin	(PS)	**Cottus asper** Richardson
Shorthead sculpin	(STHS)	**Cottus confusus** Bailey and Bond

Total number of species: 18

from the Arrow Lakes Reservoir into downstream areas. Mysids from Lower Arrow Lake constitute an important component of the diet of many fish below the Hugh Keenleyside Dam. Fish swept through the dam provide new recruits to downstream populations; however, the extent of this input is unknown. As well, the Hugh Keenleyside Dam, to a large extent, prevents the upstream movement of fish into Arrow Lakes Reservoir (i.e., limited fish passage through the boat lock is possible). Consequently, concentrations of migrating fish likely occur below the dam.

Forage and coarse fish species, especially redside shiner and juvenile suckers, contributed more than 90% to the total number of fish captured or observed in the area (Ash et al. 1981). Eight species of fish captured in the Columbia River between the Hugh Keenleyside Dam and Castlegar are regarded as sportfish. Mountain whitefish (juveniles) were the most abundant, contributing about 5% to the total number of fish captured and observed. Kokanee and rainbow trout were common also. Kokanee, rainbow trout, and Dolly Varden attract considerable angling effort below the Hugh Keenleyside Dam. Walleye abundance in this section of the Columbia River increased dramatically in 1981, a likely result of range expansion from Lake Roosevelt, Washington.

(a) Major Sport Species

i) Kokanee. Kokanee characteristically inhabit open water portions of lakes, an environment in many ways similar to the wide, deep, and slow-flowing channel between the Hugh Keenleyside Dam and Castlegar. The quality of habitat available, along with an abundance of mysids (a major component in the kokanee diet - Ash et al. 1981; Lindsay 1976) creates a high potential for kokanee rearing in the area. Kokanee were a common component of the sampling catch and angler catch in this area in 1980 (Ash et al. 1981; B.C. Fish and Wildlife Branch 1981); however, a substantial reduction in kokanee abundance occurred during the winter of 1980-81.

Reasons for this reduction can only be speculated. First, the absence of young-of-the-year kokanee in sampling catches, the limited amount of suitable spawning habitat, and the similarity in morphologic and scale

characteristics (Ash et al. 1981; Ash and Luedke 1981), suggest kokanee below the Hugh Keenleyside Dam are recruited from Lower Arrow Lake. A reduction in recruitment, therefore, may have contributed to the decline. Also, it is possible that high saturation levels of dissolved gases below the Hugh Keenleyside Dam, may have resulted in kokanee mortality thereby contributing to the decline.

It is not known whether kokanee spawn in the mainstem Columbia River between the Hugh Keenleyside Dam and Castlegar. The limited amount of suitable habitat, the large water level fluctuations, and absence of young-of-the-year kokanee in the electrofishing samples suggest they do not. Kokanee spawning does occur in Norns Creek (Km 48.6); however, differences in morphologic and scale characteristics suggest that the majority of these kokanee do not originate from the local population of kokanee, and likely migrate into the area from Lake Roosevelt (Ash et al. 1981; Ash and Luedke 1981).

ii) Rainbow Trout. Rainbow trout were a common component in sampling catches (Ash et al. 1981) and angler catches (B.C. Fish and Wildlife Branch 1981) on the Columbia River between the Hugh Keenleyside Dam and Castlegar. Rainbow trout abundance in the low gradient reaches above Castlegar was greatest in spring, and subsequently decreased through summer, fall, and winter (Ash et al. 1981; B.C. Fish and Wildlife Branch 1981). Proximity to major spawning grounds in Norns Creek probably influences springtime abundance in this region. Post-spawning downstream movement (Ash et al. 1981), likely to summer feeding areas, results in decreased summer abundance above Castlegar.

Norns Creek appears to be the major spawning area for rainbow trout in the Columbia River below the Hugh Keenleyside Dam. The 1981 spawning run into Norns Creek was estimated at 250 to 350 rainbow trout. Other spawning areas include Champion Creek and the Kootenay River below the Brilliant Dam. Other tributaries (e.g., Blueberry, China, and Murphy creeks), and the mainstem Columbia River also may be utilized for spawning by rainbow trout from the river.

iii) Dolly Varden. Dolly Varden are an important sportfish in the Columbia River, being second only to rainbow trout in angler appeal and effort (B.C. Fish and Wildlife Branch 1981). Present effort is probably directed at individuals recruited from Arrow Lakes Reservoir through the Hugh Keenleyside Dam and/or the remnants of a larger riverine population which existed prior to construction of the Hugh Keenleyside Dam.

Sampling results and angler catches indicate Dolly Varden are most abundant immediately below the dam. This may be due to the abundant food supply (i.e., small fish) in the area or the presence of the dam as a barrier to upstream movements by Dolly Varden.

Sparse information exists regarding Dolly Varden spawning in the area. Spawning by this species in Norns Creek in previous years has been reported (H. Andrusak, pers. comm.); however, no adults were noted in the creek during their probable spawning period in 1980 or 1981, and extensive electrofishing in the creek did not reveal the presence of any juvenile Dolly Varden during these years.

iv) Walleye. The abundance of walleye in sampling catches upstream of Castlegar increased dramatically from 1980 to 1981 (Ash and Luedke 1981), a result of substantial upstream movements from Lake Roosevelt. A walleye captured below the Hugh Keenleyside Dam in the fall of 1981 was tagged as part of a spawning run in the Spokane River in the spring of 1981 (Ash and Luedke 1981). The extent of upstream movement was approximately 150 km. The purpose of these movements is unknown but may be related to summer feeding activities. As the major component of the walleye diet is fish, the Columbia River between the Hugh Keenleyside Dam and Castlegar likely provides excellent feeding habitat for this species.

v) Mountain Whitefish. Juvenile mountain whitefish were abundant during sampling of the Columbia River between the Hugh Keenleyside Dam and Castlegar, indicating the suitability of the area as mountain whitefish rearing habitat. Mountain whitefish spawning habitat is limited in this low gradient section of the Columbia River; however, suitable spawning

habitat may occur in the turbulent tailwaters of the Hugh Keenleyside Dam. The limited amount of suitable mountain whitefish spawning habitat and the presence of large numbers of juveniles in the upper section of the river may indicate upstream movements by juveniles into the area from downstream (i.e., below Castlegar) spawning areas.

Adult mountain whitefish were present only infrequently in samples from this section of the Columbia River; however, they were abundant in higher gradient sections downstream of Castlegar indicating their preference for the swifter flowing, high gradient habitat.

vi) Burbot. Burbot generally were abundant in the lower gradient reaches of the mainstem Columbia River between Castlegar and the Hugh Keenleyside Dam (Ash et al. 1981). This species attracts considerable angling effort immediately below the dam during March and April; the apparent increase in abundance during this period (B.C. Fish and Wildlife Branch 1981) may result from a combination of factors. As dissolved gas concentrations decrease in early spring (a consequence of minimum utilization of the sluiceway for water release at the Hugh Keenleyside Dam), burbot may move into near surface waters. Spawning-related movements into the area may occur also (i.e., suitable burbot spawning habitat of shallow, sandy bottom areas is present).

vii) White Sturgeon. White sturgeon are known to inhabit the Columbia River within the study area. Licence sales indicate that there is an increasing sportfishery for white sturgeon in the Columbia River between the Hugh Keenleyside Dam and the International Border. Seven catch permits were issued for the Trail area in 1974; 61 permits were issued in 1980 (B.C. Fish and Wildlife Branch, unpubl. data). B.C. Fish and Wildlife Branch studies, conducted downstream of Trail in the spring of 1981, suggest a substantial population of white sturgeon inhabits the Columbia River (B.C. Fish and Wildlife Branch 1981).

The presence of young sturgeon in the Columbia River (Ash and Luedke 1981; H. Andrusak, pers. comm.) suggests spawning may occur within the study area; however, spawning locations utilized by sturgeon are not

known. Scott and Crossman (1973) report that sturgeon probably spawn over rocky bottom in swift currents, near rapids or waterfalls. Zakharyan (1972) documented three species of sturgeon (i.e., Russian, stellate, and spiny) spawning in fast water below hydroelectric dams in the Kura and Araks rivers in the U.S.S.R. Consequenty, spawning may occur in the tailwaters of the Hugh Keenleyside Dam or Brilliant Dam.

viii) Lake Whitefish. Lake whitefish are scarce in the Columbia River below the Hugh Keenleyside Dam. Incidental captures of mature individuals only in spring (1980 and 1981) and winter (1981) suggest that they do not constitute a resident population. Lake whitefish in the area may be recruited from Lower Arrow Lake or may represent an upstream spawning migration from Lake Roosevelt.

ix) Chinook Salmon. Local anglers report infrequent captures of this species immediately below the Hugh Keenleyside Dam (B.C. Fish and Wildlife Branch 1981). These fish originate from stocks planted in Lake Roosevelt during the period 1972-1978 by the Washington Department of Fisheries. There is no information regarding their abundance, distribution, or habitat preference in the Columbia River.

(b) Non-Sport Species

Coarse and forage fish species contributed more than 90% to the total number of fish captured or observed in the two low gradient reaches between the Hugh Keenleyside Dam and Castlegar (Ash et al. 1981). Redside shiner is the most abundant forage species in the area. Although redside shiners may be important competitors for rearing habitat with young-of-the-year and yearling sportfish (i.e., kokanee and rainbow trout), they likely provide an important food source for species such as rainbow trout, Dolly Varden, walleye, and northern squawfish.

Largescale and longnose suckers also were a major component of the 1980 and 1981 sampling catches. The abundance of all age classes in the Columbia River between the Hugh Keenleyside Dam and Castlegar suggests that spawning and rearing use of this area is substantial.

Other non-sport fish species encountered in the Columbia River near the Hugh Keenleyside Dam include peamouth, carp, northern squawfish, and sculpins.

3.3 MURPHY CREEK RESERVOIR FISH POPULATIONS

The potential impacts on the fisheries resources as a result of the proposed Murphy Creek Dam have been discussed in detail in the Murphy Creek Project fisheries studies by Ash et al. (1981) and Ash and Luedke (1981). The major adverse impacts of this development would be the blockage of fish migrations (e.g., kokanee, rainbow trout, sturgeon) unless fish passage facilities are included, and the loss of important or critical riverine habitat (e.g., spawning, rearing, feeding) both in the mainstem Columbia River and in the lower sections of tributary streams. This would result in an overall reduction of sportfish within the reservoir area in comparison to present riverine conditions. The species of sportfish that would be most adversely affected would be rainbow trout, mountain whitefish, and sturgeon; kokanee abundance in the reservoir, on the other hand, likely would be similar or perhaps slightly greater than would occur in the river under normal conditions, were the project not to proceed. This latter prediction was based on the assumption that the kokanee that contribute to the sportfishery below the Hugh Keenleyside Dam are primarily fish that have been displaced from Lower Arrow Lake.

The major beneficial impact of the Murphy Creek Project would be the reduction of high total dissolved gas concentration below the Hugh Keenleyside Dam during most of the year as a result of higher tailwater elevations. The overall effect of the reduced saturation levels on the downstream fish populations is unknown.

SECTION 4
EFFECTS OF DEVELOPMENT

4.1 PROJECT DESCRIPTION

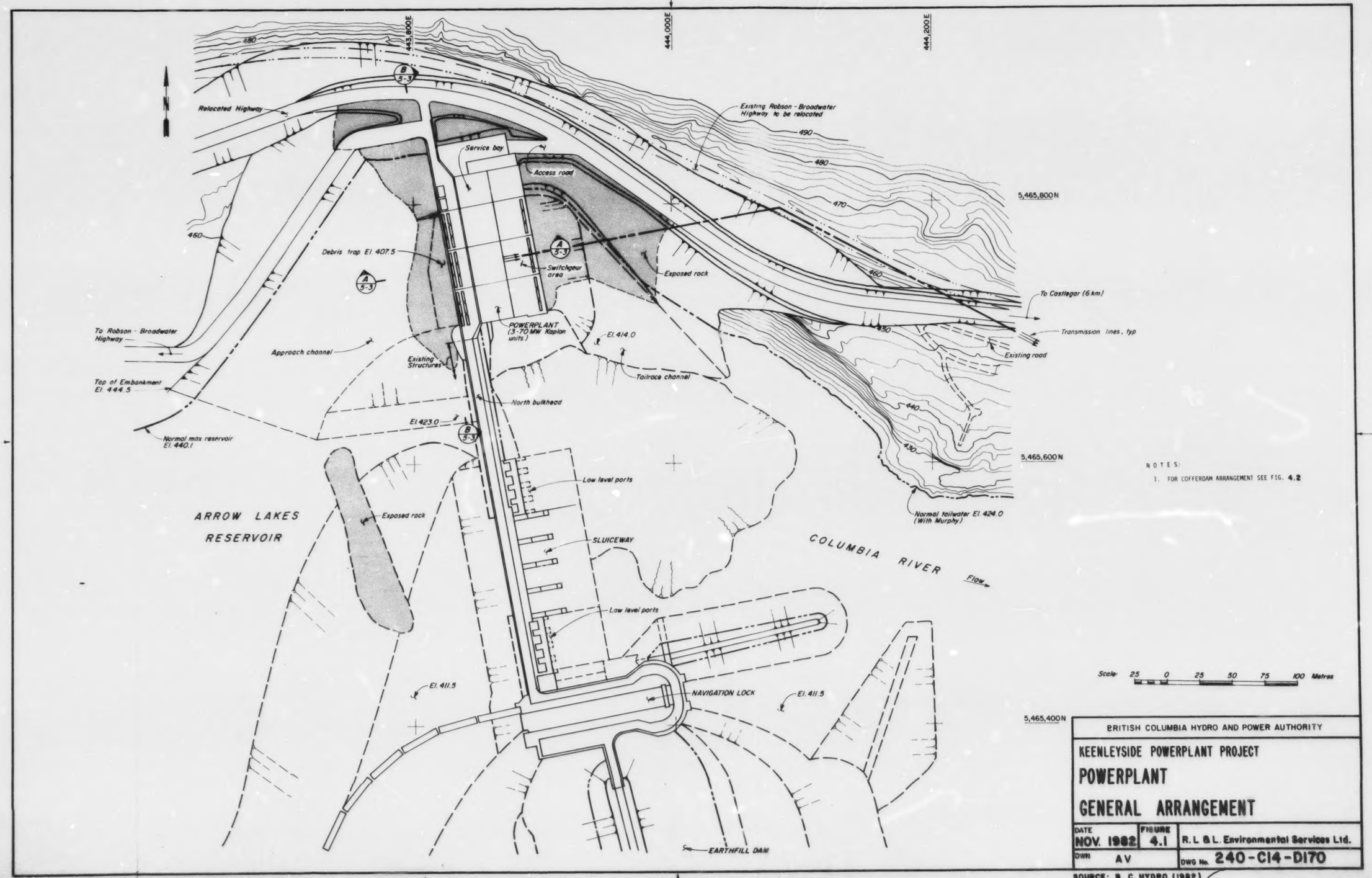
4.1.1 PHYSICAL FEATURES

An engineering description of the Keenleyside Powerplant project has been provided by B.C. Hydro (1982). Much of the description that follows has been extracted from that report. The Keenleyside Powerplant Project would involve the installation of three vertical axis Kaplan turbines and generators. The powerhouse would be located on the north bank, between the existing discharge facilities at the Hugh Keenleyside Dam and the Robson-Broadwater Highway (Figure 4.1). The powerhouse would be constructed adjacent to the end of the existing north bulkhead section of the dam, and would have a short intake approach channel connected to the reservoir immediately upstream of the dam.

The approach channel leading from the reservoir to the proposed generating facilities on the north bank would have an average length of about 150 m and a maximum width of about 230 m near the channel entrance. The invert level at the entrance would be at el. 423 m, and the channel would angle downward to the debris trap in front of the powerplant intake (Figure 4.2). The approach channel would be protected against wave and scour action by a riprap covering with a sand and gravel bedding.

The powerplant intakes for each unit would consist of three bays separated by piers, trashracks at the upstream face, guides for service bulkheads or stoplogs a short distance downstream, and hydraulically raised or lowered operating gates. Although the design of the trashracks has not been finalized, they may consist of steel bars placed at approximately 18 to 20 cm centre to centre (J. Muralt, B.C. Hydro, pers. comm.).

The three turbines would be vertical shaft Kaplan units operating at 66.67 rpm. The rated discharge of each of the three units would be approximately 500 m^3/s for a combined three-unit powerplant discharge of 1500 m^3/s (based on the 210-MW installed capacity design). The adjustable blades on the Kaplan turbines will result in high efficiency and minimum cavitation over the wide range in head (i.e., 7.0 to 16.7 m gross head).



NOTES:

1. FOR COFFERDAM ARRANGEMENT SEE FIG. 4.2

Scale: 25 0 25 50 75 100 Metres

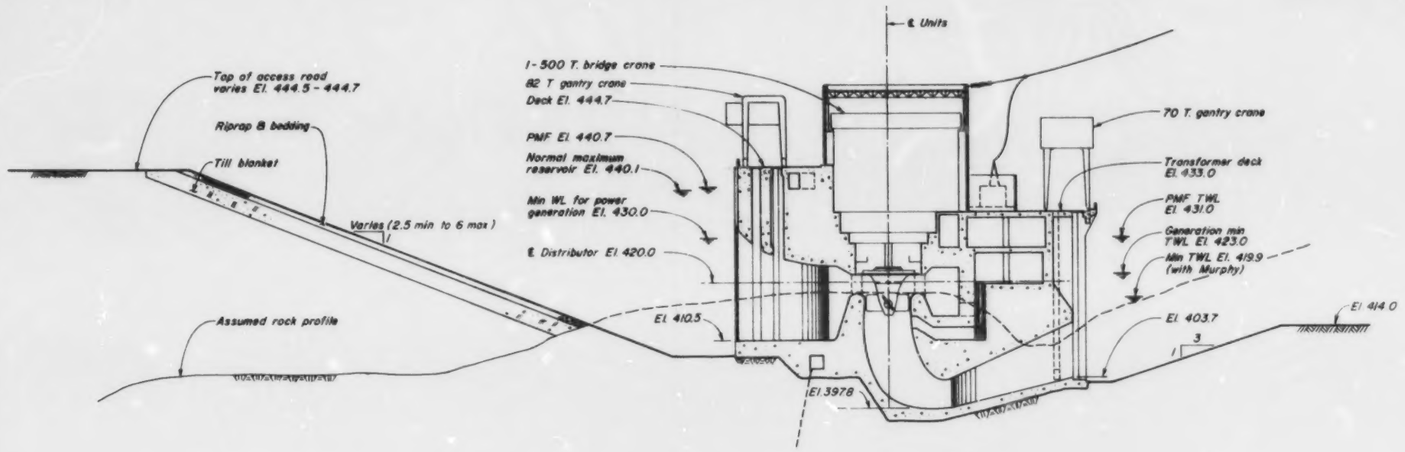
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

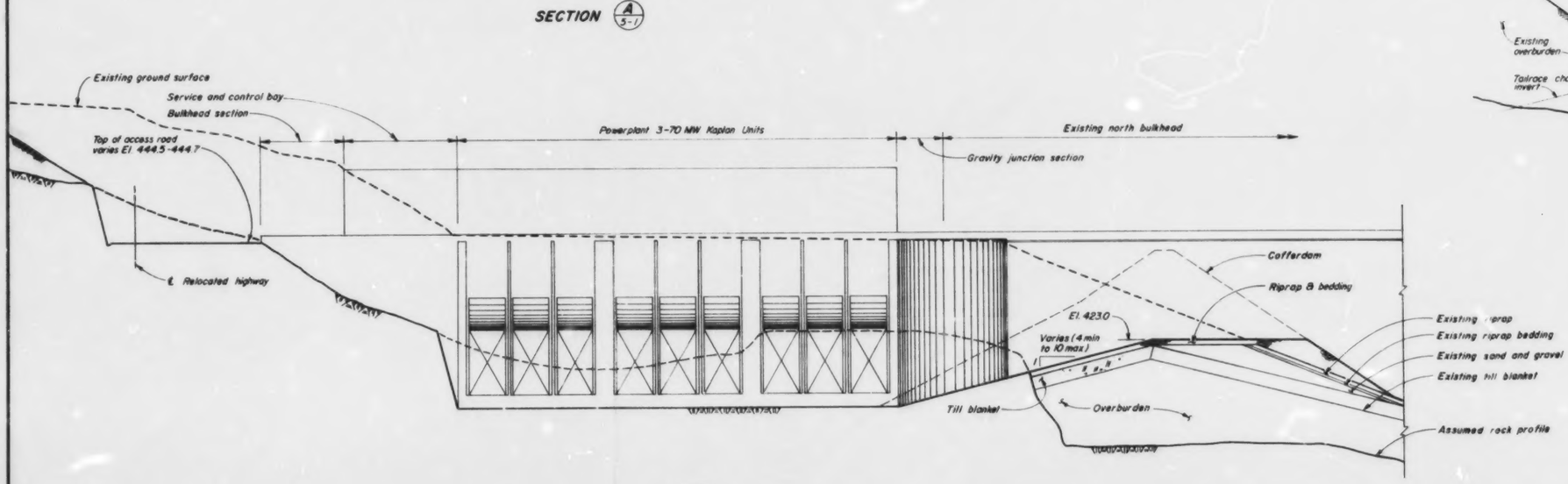
POWERPLANT GENERAL ARRANGEMENT

DATE	FIGURE	
NOV. 1982	4.1	R. L. & L. Environmental Services Ltd.
DWN AV		DWG No. 240-C14-D170

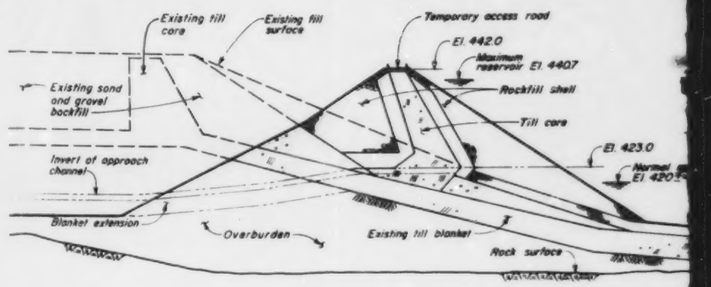
SOURCE: B. C. HYDRO (1982)



SECTION (A 5-1)

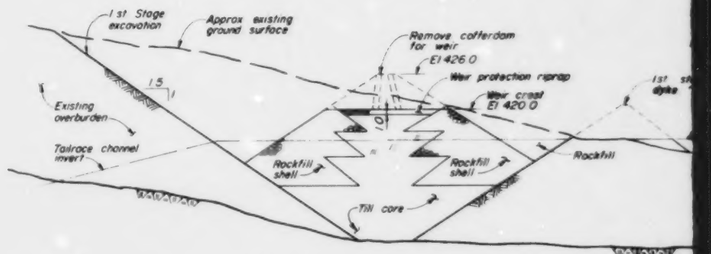


SECTION (B 5-1)



SECTION (C 5-2)

UPSTREAM COFFERDAM



SECTION (D 5-2)

DOWNSTREAM COFFERDAM

Scale: 10 0

BRITISH COLUMBIA

KEENLEYSIDE POWER

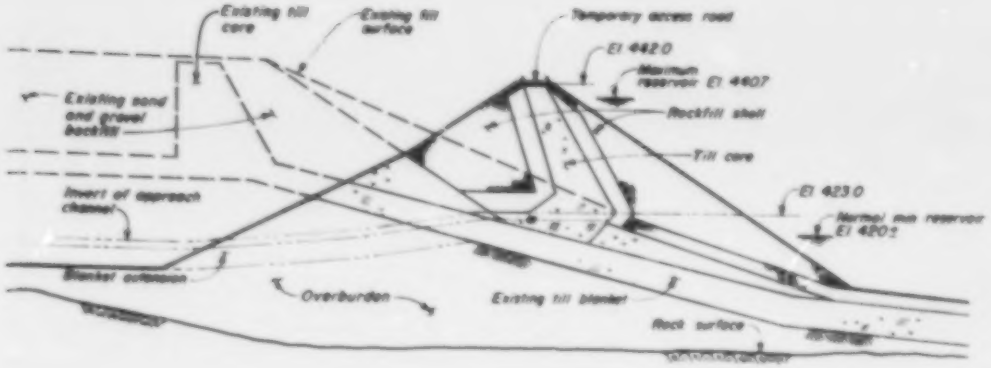
POWERPLANT & SECTIONS

DATE NOV. 1982

FIGURE 4.2

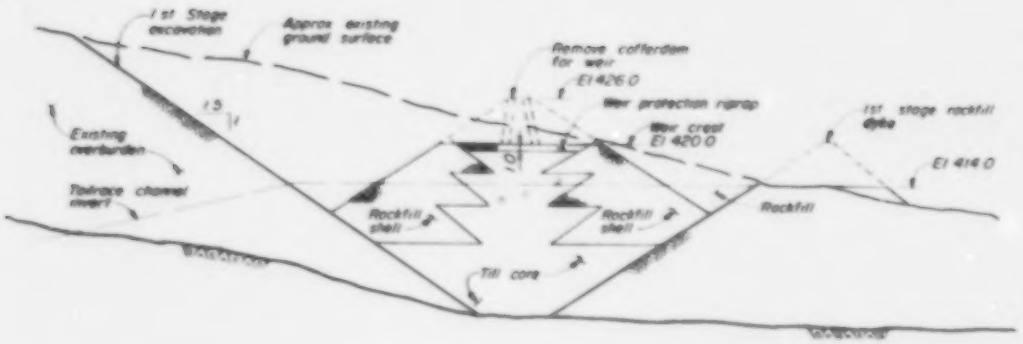
DWN FL/SM

SOURCE: B.C. HYDRO



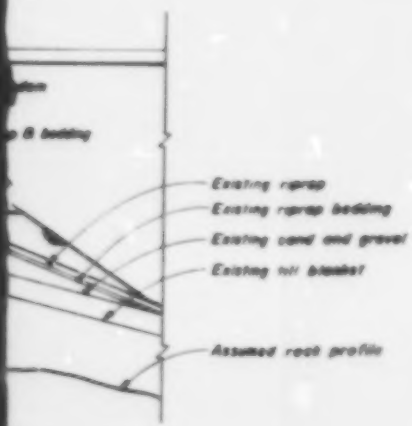
SECTION C/S-2

UPSTREAM COFFERDAM



SECTION D/S-2

DOWNSTREAM COFFERDAM



Scale 10 0 10 20 30 40 Metres

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

POWERPLANT & COFFERDAMS SECTIONS

DATE	FIGURE	
NOV. 1982	4.2	R.L & L. Environmental Services Ltd.
DWN FL/SM		DWG No. 240-C14-U171

SOURCE: B. C. HYDRO (1982)

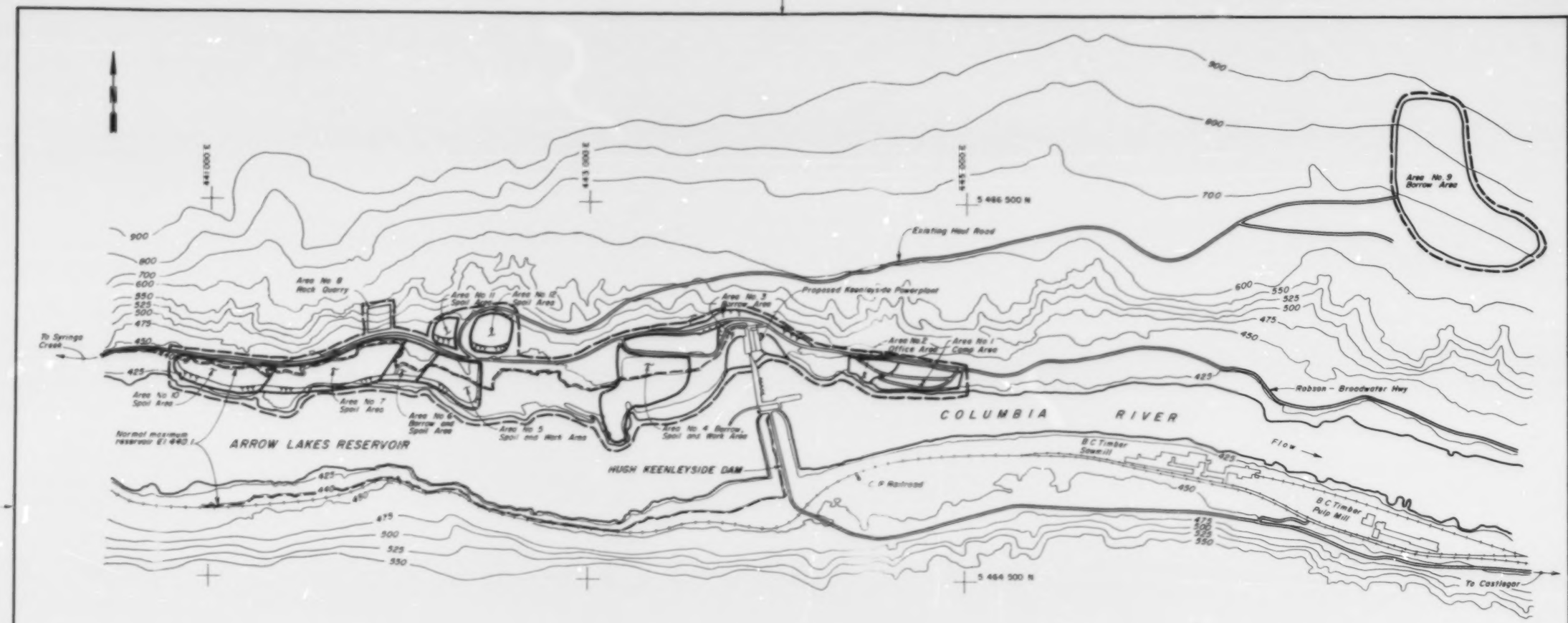
The tailrace channel would be approximately 150 m long, with an invert width of 60 to 70 m. The tailrace channel would angle sharply towards the existing river channel. As a result, some turbulence is expected in this area during operation of the sluiceway and low level ports, so the tailrace channel will be lined with riprap to above the maximum tailwater levels. The maximum water velocity expected in the tailrace channel will be approximately 2 m/s.

Ancillary facilities or construction activities associated with the project will involve the construction and operation of a work camp for about 320 workers on the terrace on the north side of the river approximately 0.7 km downstream of the Hugh Keenleyside Dam, the realignment of about 1200 m of the Robson-Broadwater Highway, the construction of transmission facilities, the excavation of gravel materials from borrow areas, and the disposal of some $1.6 \times 10^6 m^3$ of excavated silts, sands, gravels, and rock. Figure 4.3 illustrates the location of potential areas for construction facilities including the construction camp, and the 12 potential borrow and spoil disposal sites.

4.1.2 OPERATING REGIME

Two operating regimes have been considered for the Keenleyside Powerplant Project and the Arrow Lakes Reservoir. The existing operating regime (Regime 1) for the Arrow Lakes Reservoir, as dictated by the Columbia River Treaty, requires that the reservoir be drawn down from its normal maximum level at el. 440.1 m (in high runoff years, the reservior may be surcharged to el. 440.7 m) to the minimum level at el. 419.6 m by 1 May of each year if necessary to provide up to $8.8 \times 10^9 m^3$ of useable storage. A summary of monthly mean Arrow Lakes Reservoir water levels, tailrace levels, and the discharge at the Hugh Keenleyside Dam under Regime 1 is shown in Figure 4.4.

Under Regime 1 the only change in the operating regime that would be attributable to generating facilities at the Hugh Keenleyside Dam would be the diversion of approximately 55% of the total annual discharge from the sluiceway and low level ports to the powerplant. However, since the powerplant would not be operating during the mid-January to mid-June period, all discharge during this period would be through the sluiceway or low level ports. This report assumes that the timing and extent of drawdown of the Arrow Lakes Reservoir under


441 000 E
443 000 E
445 000 E
5 466 500 N
5 464 500 N
Area No. 9 Borrow Area
Existing Haul Road
Proposed Keenleyside Powerplant
Area No. 8 Rock Quarry
Area No. 11 Spoil Area
Area No. 12 Spoil Area
Area No. 3 Borrow Area
Area No. 2 Office Area
Area No. 1 Camp Area
To Syringa Creek
Area No. 10 Spoil Area
Area No. 7 Spoil Area
Area No. 6 Borrow and Spoil Area
Area No. 5 Spoil and Work Area
Area No. 4 Borrow, Spoil and Work Area
Normal maximum reservoir El 440 ft
ARROW LAKES RESERVOIR
HUGH KEENLEYSIDE DAM
COLUMBIA RIVER
Flow
Robson - Brodwater Hwy
C P Railroad
B C Timber Sawmill
B C Timber Pulp Mill
To Castlegar
LIMIT OF CONSTRUCTION AREAS
Scale 200 0 200 400 600 800 Metres

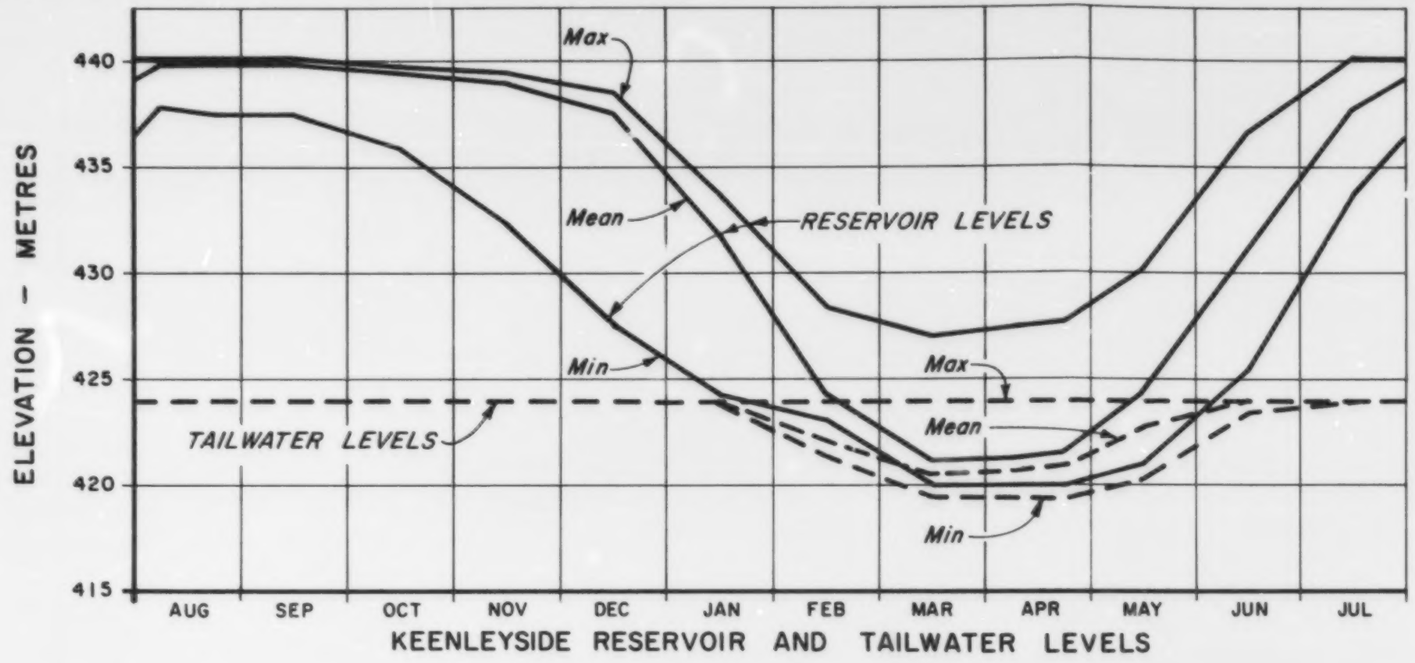
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

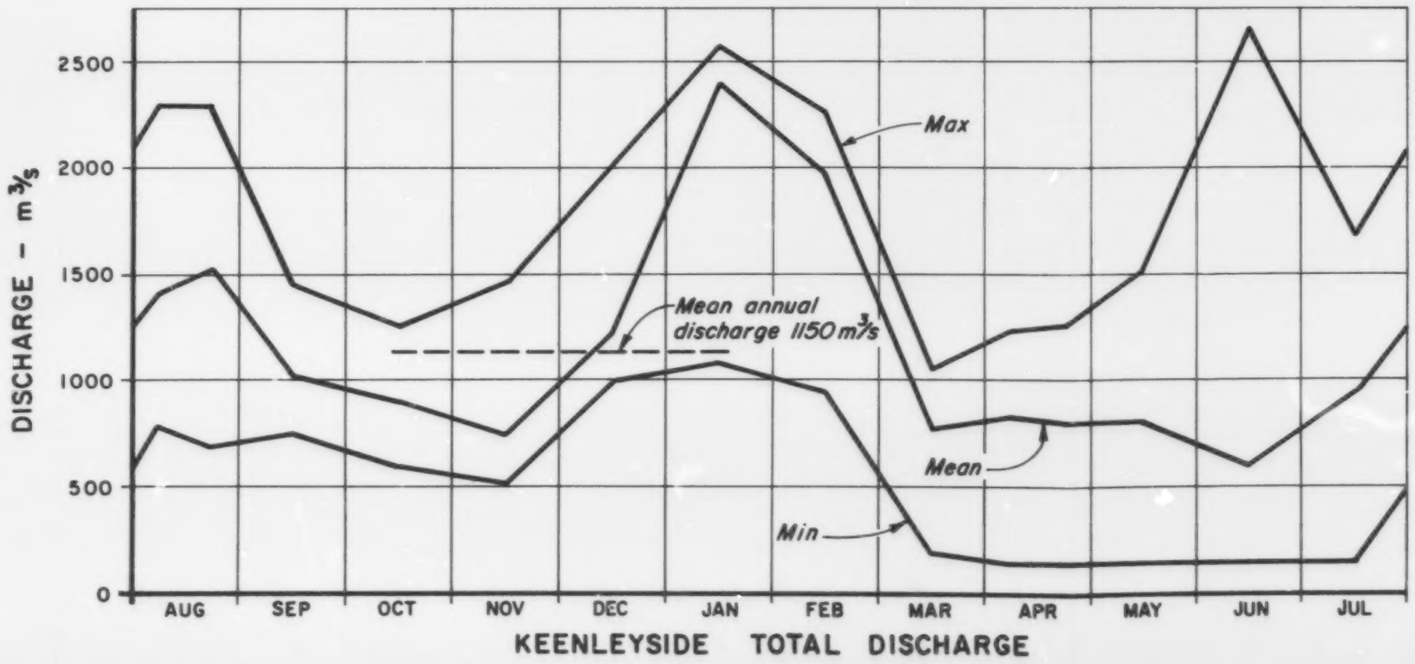
POTENTIAL AREAS FOR CONSTRUCTION FACILITIES

DATE	FIGURE	
NOV. 1982	4.3	R.L & L Environmental Services Ltd.
DWN SM		DWG No. 240-C14-D173

SOURCE: B. C. HYDRO (1982)



KEENLEYSIDE RESERVOIR AND TAILWATER LEVELS



KEENLEYSIDE TOTAL DISCHARGE

NOTE:

KEENLEYSIDE TAILWATER LEVELS ARE BASED ON A MURPHY CREEK PROJECT RESERVOIR ELEVATION LIMIT OF 424.0 m AT CASTLEGAR.

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

TYPICAL RESERVOIR LEVELS & DISCHARGE HYDROGRAPHS - EXISTING OPERATION (REGIME 1)

DATE	FIGURE	
NOV. 1982	4.4	R.L B L. Environmental Services Ltd.
DWN KL		DWG. No 240-C14-B168

SOURCE: B. C. HYDRO (1982)

ROBB OWENS - 5164

Operating Regime 1 would not change from present conditions (i.e., without the project).

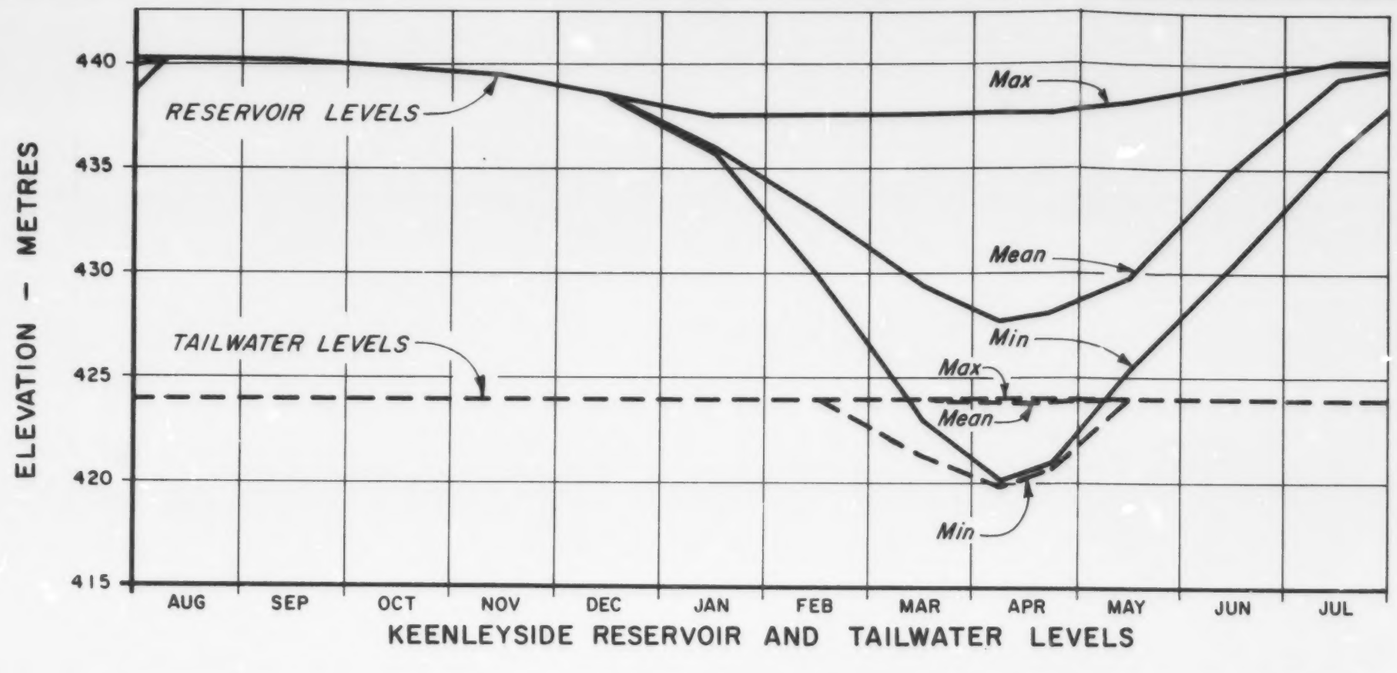
Under Regime 2, the hydraulic heads at both the Hugh Keenleyside Dam and the Murphy Creek Dam would be maximized for power production, and to reduce potential adverse environmental effects caused by reservoir drawdown. This operating regime involves the reduction of about 2.5 x $10^9 m^3$ in the mean annual drawdown volume of the Arrow Lakes Reservoir, and an increase of about 6.6 m in the mean annual minimum reservoir level (i.e., reduced drawdown; B.C. Hydro 1982). A summary of the monthly mean reservoir levels, tailwater levels and discharges for the future Regime 2 is shown in Figure 4.5.

Under mean water conditions with Regime 2, the Murphy Creek Reservoir, in most years, would not have to be drawn down to permit the Keenleyside releases. Under this regime, approximately 73% of the total annual flow at the Hugh Keenleyside Dam will pass through the turbines. Discharge through the sluiceway would be reduced from approximately 68% of total annual flow to about 1.5% (Regime 1) or 3% (Regime 2).

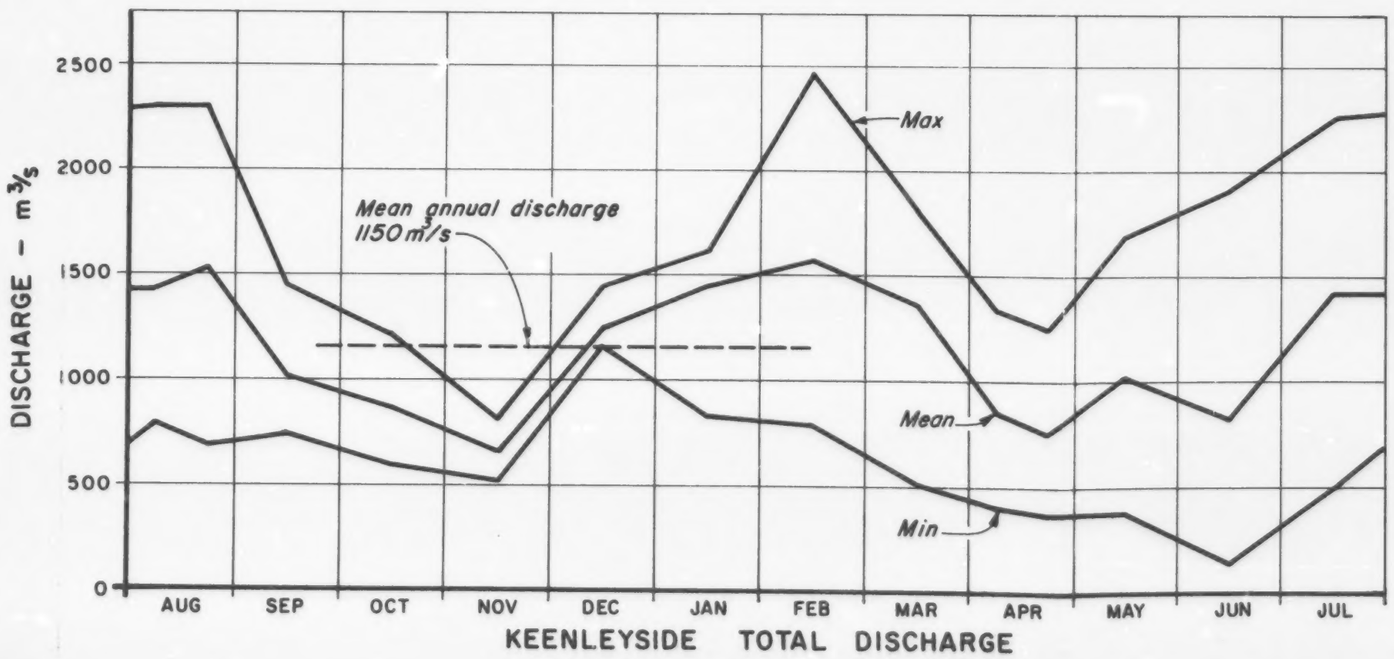
Although the power generation facilities both for the Keenleyside Powerplant Project and the Murphy Creek Project have been designed to allow operation under Regime 2, it is likely that initially the projects will be operated under Regime 1.

4.1.3 CONSTRUCTION SCHEDULE

The construction of the Keenleyside Powerplant Project would require approximately 5½ years. Based on the 1983/84 B.C. Hydro System Plan, assuming an Energy Project Certificate is received by 1 January 1985, construction would begin in September 1986 with the first unit being in-service in August 1992, the second unit following in December, and the third unit in August of 1993. The Keenleyside Powerplant Project, therefore, would be completed approximately one year prior to completion of the Murphy Creek Project (proposed in-service date of June 1993).



KEENLEYSIDE RESERVOIR AND TAILWATER LEVELS



KEENLEYSIDE TOTAL DISCHARGE

NOTE:

KEENLEYSIDE TAILWATER LEVELS ARE BASED ON A MURPHY CREEK PROJECT RESERVOIR ELEVATION LIMIT OF 424.0 m AT CASTLEGAR.

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

TYPICAL RESERVOIR LEVELS & DISCHARGE HYDROGRAPHS - FUTURE OPERATION (REGIME 2)

DATE	FIGURE	
NOV. 1982	4.5	R.L & L. Environmental Services Ltd.
DWN KL		DWG. No 240-C14-8169

SOURCE: B. C. HYDRO (1982)

HUGHES OWENS - 5154

4.2 DESIGN AND PRE-CONSTRUCTION PHASE

During the design and pre-construction phase of the project, a number of activities associated with the project could result in terrain disturbance (e.g., test drilling on site, borrow area testing) which, in turn, may cause increased suspended sediment input into the Columbia River or Lower Arrow Lake. However, due to the small amount of terrain likely to be disturbed, the effects of the pre-construction activities on fish and fish habitat in downstream areas are expected to be negligible provided effective erosion control measures are employed. Other pre-construction activities expected to have a negligible effect on the fisheries resource include possible biological sampling programs, and increased angling pressure that may result from additional people directly associated with the project (i.e., B.C. Hydro employees, consultants, drilling crews, etc.) being in the area.

4.3 CONSTRUCTION PHASE

The major effects on the fisheries resource that may accrue due to construction activities would be associated with the following:

(1) alterations to water quality, primarily downstream of the construction site;

(2) increased angling pressure;

(3) the use of explosives during site excavation or cofferdam removal; and

(4) the construction of ancillary facilities.

4.3.1 WATER QUALITY

A number of construction activities associated with the Keenleyside Powerplant Project could result in increased levels of suspended sediment entering Lower Arrow Lake, or the Columbia River downstream of the Hugh Keenleyside Dam. Sediment input could result from terrain disturbances (i.e., road realignment, grading of slopes, borrow material removal, etc.), aggregate washing activities, in-water construction activities (i.e., cofferdam construction or removal both in Lower Arrow Lake and in the Columbia River downstream of the dam), and erosion along the dykes around spoil disposal areas (i.e., some

$1.6 \times 10^6 m^3$ of excavated silts, sands, gravels, and rock would have to be disposed of, likely on the north bank of the reservoir approximately 1 to 3 km upstream of the dam; see Figure 4.3).

High levels of suspended sediment and subsequent substrate siltation have been shown to adversely affect fish, fish egg incubation, and many benthic organisms (i.e., organisms often utilized as fish food) in a riverine environment (Wallen 1951; Cordone and Kelley 1961; European Inland Fisheries Advisory Committee 1964; Hall and Lantz 1969; Hynes 1970). Important sportfish species rear and/or spawn in the Columbia River below the Hugh Keenleyside Dam (e.g., mountain whitefish, burbot, rainbow trout, kokanee) and high levels of suspended sediments entering the system as a result of construction at the dam could potentially have a detrimental effect on these species. Since the aquatic organisms in the Columbia River are presently adapted to clear water conditions, they likely are more susceptible to increases in turbidity and substrate sedimentation than are organisms in streams with high suspended sediment levels. The overall effects of the increased suspended sediment levels on the aquatic resources in the study area largely will be dependent on the extent to which erosion of the disturbed area is controlled, and the extent to which effluents from activities such as gravel washing are treated prior to discharge into the system. Short-term increases in suspended sediment levels from other construction activities are inevitable (e.g., cofferdam installation/removal, placement of riprap, etc.). These short-term increases in suspended sediment levels would have a detrimental effect on downstream fish populations, with the magnitude of the effect being dependent on the volume and duration of sediment input (i.e., short-term minor increase would have minor effect).

A decrease in water quality downstream of the construction site also may occur if toxic materials such as oils, greases, drilling fluids, chemicals, or untreated sewage are accidentally introduced into the watercourse. These materials can cause direct fish mortality, or affect fish indirectly by reducing oxygen levels (resulting from aerobic breakdown) or by reducing the number of fish food organisms present in the system. With proper precautionary measures, the chances of an accidental introduction of toxic materials is remote; however, due to the large numbers of fish that concentrate immediately below the Hugh Keenleyside Dam, a spill of any highly toxic materials could affect a large

nunber of important sportfish. The spill or seepage of oils, greases, phenols, etc. into the Columbia River also could affect the sportfishery even at non-toxic concentrations by tainting the taste of the fish. The presence of a sizeable population of sportfish (e.g., rainbow trout, Dolly Varden, walleye, kokanee) immediately downstream of the project site would increase the potential for this impact (i.e., little opportunity for dilution) if a spill occurred.

The construction of the Keenleyside Powerplant Project would result in additional workers moving into the area for the construction period. Although a high percentage of the workers are expected to be drawn from the local area, a work camp facility has been included in project plans, to house the non-local workforce. The camp would be constructed on the terrace on the north side of the river approximately 0.7 km below the Hugh Keenleyside Dam. The projected workforce residing in the camp would be up to 320 (B.C. Hydro 1982). At the present time, plans call for the sewage from the work camp to be treated to meet the B.C. Waste Management Branch requirements prior to discharge into the Columbia River (P. Maxymuik, pers. comm.). The treatment facility would be designed to handle an effluent of 230 L/capita/d or a total expected discharge for the 320 person camp of 73 600 L/d. The average daily total phosphorus loading concentration for the Columbia River at the Hugh Keenleyside Dam is about 724 kg/d as total P (B.C. Ministry of Environment 1976-79 in IEC 1981). Assuming that treatment at the construction camp would satisfy suggested total phosphorus objectives for effluents (i.e., 0.1 mg/L - Clark 1980), an additional maximum of 7360 mg of P (or 7.36 g of P) per day would enter the Columbia River. This small addition to the daily phosphorus load would not have any detrimental effect on the aquatic resources of the Columbia River. Due to the relatively small volume of the expected effluent in relation to the large flow of the Columbia River, it is expected that the river could adequately assimilate this effluent without significantly decreasing downstream water quality, providing treatment meets the B.C. Waste Management Branch standards. Due to the relatively low nutrient (i.e., nitrogen, phosphorus, etc.) levels in Lower Arrow Lake and, therefore, the Columbia River, the additional input of these nutrients as a result of the treated sewage discharge may have a short-term moderate fertilization or enrichment effect on the river. This likely would result in a

minor increase in benthic algae and zoobenthos production in downstream sections of the river which, in turn, could increase fish productivity.

The use of nitrogen-based explosives for excavation has been shown in some circumstances to increase nitrate levels in runoff or seepage water from the area which, in turn, can cause problems in receiving tributaries by increasing growths of benthic algae (R. Crozier, pers. comm.). The use of explosives during excavation at the Hugh Keenleyside Dam may similarly increase nitrate levels in runoff or seepage waters. However, since most of the excavation will be conducted in the dry (i.e., behind the cofferdams), with the excavated material removed to the disposal sites, increases in nitrate levels in seepage waters from the excavation area are not expected to cause any substantial detrimental effects on the downstream river system. As discussed previously, a small increase in nutrient levels may actually be beneficial to downstream fish populations by increasing benthic productivity.

4.3.2 INCREASED ANGLING PRESSURE

The construction of the Keenleyside Powerplant Project would require a peak workforce of approximately 540 workers (B.C. Hydro 1982). Of these, the majority would likely will be drawn from the local workforce (DPA, 1983). With the influx of these additional workers, their families, and additional service personnel into the project area, the angling pressure in the study area likely would increase. In addition, the proposed location of the work camp (for up to 320 persons) immediately adjacent to the most popular angling location along the river (i.e., the north bank of the river immediately downstream of the Hugh Keenleyside Dam) would result in a large increase in angling effort in this area. This, in turn, may result in an overharvest of the fish stocks in this and other adjacent areas.

4.3.3 USE OF EXPLOSIVES

Underwater blasting often causes high mortalitiy to fish in the vicinity of the explosion (Coker and Hollis 1950; Ferguson 1961; Paterson and Turner 1968; Falk and Lawrence 1973; McDonald 1973; Wright 1982). Fish mortalities could result if explosives are used in or near the river channel during site

excavation or cofferdam removal during construction of the Keenleyside Powerplant. The magnitude of this potential effect will be dependent on the extent of use of the explosives, and the numbers of fish near the site. Since large numbers of sportfish (primarily rainbow trout, Dolly Varden, and burbot) are present along the north bank of the river immediately downstream of the Hugh Keenleyside Dam, the use of explosives during the downstream cofferdam removal (if required) would have the greatest potential for causing fish mortalities.

4.3.4 ANCILLARY FACILITIES

The construction of ancillary facilities such as borrow areas, disposal sites for excavated material, etc. could result in additional detrimental impacts on the fisheries resources in the area; however, since the major effects will accrue from increases in suspended sediments entering the watercourses (as discussed in Section 4.3.1), the effects on fish populations are expected to be minor if proper construction practices and effective erosion control methods are employed. The construction and maintenance of the transmission lines also may affect fish populations. An assessment of the impacts of the transmission facilities is being carried out as a separate study (Tera 1983).

4.4 OPERATIONAL PHASE

4.4.1 ARROW LAKES RESERVOIR PRODUCTIVITY

Operation of the Keenleyside Powerplant Project under Regime 1 is not expected to have any significant effect on the biological productivity in the Arrow Lakes Reservoir. Under Regime 2, however, the average annual drawdown of the reservoir would be reduced by about 6.6 m. This is expected to have a minor beneficial effect on the biological productivity of the reservoir. However, the remaining average drawdown of approximately 14 m would continue to limit biological productivity (especially fish productivity) in the reservoir.

4.4.2 EFFECTS ON DOWNSTREAM FISH PASSAGE AND SURVIVAL

Although major fish migrations likely do not occur past the Hugh Keenleyside Dam, it appears that downstream displacement of fish from the

Arrow Lakes Reservoir contributes to the sportfish populations in the Columbia River below the dam. Although definitive proof is not available, existing information indicates that the majority of the kokanee in the upper section of the Columbia River likely are recruited from Lower Arrow Lake via passage through the Hugh Keenleyside Dam (Ash et al. 1981). Other sportfish species (e.g., Dolly Varden, rainbow trout) likely also are displaced from Lower Arrow Lake. However, no information exists relating to the numbers, timing, or the life stage of the fish leaving the reservoir.

Fish presently displaced from Lower Arrow Lake are carried by the flow through the sluiceway, through the low level ports, or through the boat lock. The percentage of fish utilizing each of these exits is unknown, but it is likely that the majority of the fish pass through the sluiceway or ports due to the much higher flow through these exits in comparison to the boat lock. Since discharge through the low level ports occurs only at low reservoir elevations (i.e., generally below el. 430 m), the relative percentage of fish moving through the sluiceway in comparison to ports may be more dependent on seasonal timing of the releases, than the rate or volume of flow.

Mortalities of fish passing over or through spillways or sluiceways of low head dams have been shown to be low (Muir and Ruus 1961), although the variability in structure design, size and species of fish, etc. permit only a general statement to this effect. Volume of discharge, pressure change, impact, abrasion, velocity, shearing, and spillway and bucket design have been found by investigators to relate to the incidence of death and injury (Bell and Delacy 1972).

During a 3-year study at McNary and Big Cliff Dams in the USA, mortality of fish passing over the Ogee type spillways was estimated to be 2% (95% confidence interval of 0 to 4%) (Schoeneman et al. 1961). Although the spillway type (Ogee) was similar to the sluiceway of the Hugh Keenleyside Dam, the total head at Big Cliff Dam (27.4 m) and at McNary Dam (25.9 m) was higher than at the Hugh Keenleyside Dam (head up to 16 m).

The design of the stilling basin and energy dissipator below the sluiceway at the Hugh Keenleyside Dam may contribute to mortality. Schoeneman et al. (1961) suggest that baffle type basin structures may kill fish by abrasion or by

impact with the energy dissipators although model studies indicated that mortalities resulting from this cause likely would not be significant. However, Copp (1968) in an examination of stilling basin hydraulics at Columbia River dams, found that for certain designs (e.g., Ogee spillway with baffles at Bonneville Dam), impact injuries likely would occur. These authors noted that the back-roll created in stilling basins also may contribute to mortalities by entraining fish and by resubjecting them to the pressures and forces where the main jet (i.e., spillway flow) enters the stilling basin. The design of the energy dissipator in the stilling basin below the Hugh Keenleyside Dam likely creates a back-roll which may have effects similar to those described above by Shoeneman et al. (1961) and Copp (1968).

Upon completion of the proposed Murphy Creek Project, the tailwater elevation at the Hugh Keenleyside Dam would be at el. 424 m throughout the year under Regime 2, and throughout the June to January period under Regime 1 in most years. The tailwater elevation at that time would be only 0.9 m below the crest of the sluiceway. Because of this very small head differential, it is likely that mortality to fish passing through the sluiceway at that time would be very low.

Mortalities associated with fish passing through low level ports is not well documented in the literature. Andrew and Geen (1958) report that a mean mortality rate of 1.2% occurred during the passage of sockeye salmon smolts through the siphon at the Seaton Creek hydroelectric installation in British Columbia. They indicated that abrasions on the concrete inner surface appeared to be the primary cause of injury. The applicability of the study to mortalities of fish passing through the ports at the Hugh Keenleyside Dam is unknown; however, it appears that mortality of fish passing through the ports likely would be low.

After installation of the proposed generating facilities at the Hugh Keenleyside Dam, between 55% (Regime 1) and 73% (Regime 2) of the total annual discharge will be diverted from the sluiceway and ports to the powerplant (Table 4.1). If it is assumed that the fish displaced from Lower Arrow Lake are distributed in proportion to the rate of flow, a significant number of fish will pass through the turbines. The mortality rate of fish passing through the

Table 4.1 Percentage of total flow passing through the Hugh Keenleyside Dam sluiceway, ports, and powerplant (source: B.C. Hydro, unpublished data).

Case	Percentage of Total Flow		
	Sluiceway	Ports	Powerplant (210 MW)
Without Keenleyside Powerplant			
Operating Regime 1	68%	32%	-
With Keenleyside Powerplant			
Operating Regime 1	1.5%	43.5%	55%
Operating Regime 2	3%	24%	73%

powerplant compared to through the sluiceway or ports is unknown, but may be important if the mortality adversely affects the rate of recruitment and, hence, yield of the downstream fisheries.

A number of studies of fish mortality in turbines have been conducted; many of these have been reviewed by Bell et al. (1967) and Turbak et al. (1981). A variety of factors has been shown to contribute to mortality during turbine passage. Ruggles and Collins (1981) listed these as:

(1) mechanical damage due to contact with fixed or moving equipment;

(2) pressure-induced damage due to exposure to low pressure conditions within the turbines;

(3) shearing action damage due to passage through areas of extreme turbulence or boundary conditions; and

(4) cavitation damage due to exposure to regions of partial vacuum.

Bell et al. (1967) concluded that for Kaplan turbines (proposed for Keenleyside Powerplant), important variables affecting mortality were head (affecting velocity) and sigma (a measure of cavitation potential). Wicket gate openings and fish length (of the juvenile fish tested) had little effect on fish mortality in Kaplan turbines.

These variables may be important to potential turbine mortalities at the Hugh Keenleyside Dam and the effect on downstream fisheries in the Columbia River. Because of the low head (16.7 to 7.0 m gross), high sigma values of the proposed turbine installation (estimated 0.7 to 2.23; B.C. Hydro unpubl. data), the potential for cavitation and thus damage to fish should be low. Fish mortality from injury other than mechnical is proportional to the amount of cavitation in the turbine (Ruggles and Collins 1981). The large clearances between the blades of the Kaplan turbine and the low runner speed (i.e., 66.67 rpm; B.C. Hydro 1982) will reduce direct mechanical damage to fish, although a variety of shearing forces near the blades may still cause physical damage. Some mortalities likely still would occur; Turbak et al. (1981) state that mortality estimates of 5 to 10% appear inevitable even with the highest operating efficiency of either Kaplan or Francis turbines. Mechnical injury has not been identified as an important cause of mortality in Kaplan turbines;

however, passage has been studied primarily with juvenile salmonid fishes and no systematic introductions of larger fish have been carried out. Larger adult fish (i.e., adult kokanee, rainbow trout, or Dolly Varden) entering the turbines at the Hugh Keenleyside Dam likely could be expected to undergo higher turbine inflicted mortalities than juveniles of the same species; the significance of this would depend upon the relative contribution of various size classes to downstream fisheries.

As the turbines at the Hugh Keenleyside Dam generally would be inoperative under Regime 1 from mid-January to mid-June in most years, there would be no turbine related mortalities during approximately 37% of the year. Under Regime 2, the turbines generally would be inoperative from early March to mid-May (21% of the year). As no data are available relating to seasonal timing of fish displacement past the dam, the significance of this shut-down period is unknown.

In summary, mortalities of fish passing through the turbines likely would be higher than existing mortalities from passage through the low level ports and sluiceway. With higher tailwater elevations associated with the Murphy Creek Project (i.e., el. 424 m), mortalities through the sluiceway should be negligible, thereby leaving the primary source of mortality associated with turbine operation. Due to the greater flow passage and longer operation of the turbines under Regime 2, mortalities would likely be slightly higher in comparison to Regime 1. It is expected that this would result in a minor decrease in recruitment to the Columbia River sportfishery. Since no quantitative data are available with respect to the importance of recruitment from Lower Arrow Lake, it is difficult to speculate further on the overall significance to the sportfishery. B.C. Hydro is planning to undertake additional studies to access recruitment from Arrow Lakes through the Hugh Keenleyside Dam during 1983.

4.4.3 POTENTIAL EFFECTS ON **MYSIS** MOVEMENT OUT OF ARROW LAKE

The addition of a generating capacity at the Hugh Keenleyside Dam is not expected to significantly affect the downstream transport of **Mysis relicta** and other zooplankton from the Arrow Lake Reservoir to the Columbia River. This conclusion is based on the fact that the crest elevation of the intake

channel to the power facility (el. 423 m) is not substantially different from the crest elevation of the sluiceway (el. 424.9 m). However, if current flow patterns in front of the powerplant intake channel differ significantly from the current patterns in front of the sluiceway, small changes in the number of organisms which become entrained during powerplant operations may occur.

4.4.4 EFFECTS ON DOWNSTREAM TOTAL DISSOLVED GAS SATURATION

Available information indicates that the high total dissolved gas (TDG) levels that occur in the Columbia River below the Hugh Keenleyside Dam are caused when large volumes of water are discharged through the sluiceway at the dam. Addition of the generating capacity in the dam will divert from 55% (Regime 1) to 73% (Regime 2) of the total annual discharge from the sluiceway and low level ports to the powerplant (B.C. Hydro 1982). Since the discharge capacity of the powerplant will be approximately 1500 m^3/s, use of the sluiceway will continue to be required to pass additional flow whenever the forebay elevation is above approximately 433 m (i.e., low level ports can be used when the head differential is less than 9 m). After installation of the Keenleyside Powerplant, only 1.5% (Regime 1) or 3% (Regime 2) of the total flow will be passed through the sluiceway, in comparison to 68% of the total flow that is passed through the sluiceway under the present operating regime. Preliminary calculations made by B.C. Hydro (memo from C.Y. Wu and P. Banks to J.B. Muralt dated 15 February 1983) indicate that during high flow periods when discharge through the sluiceway is required, TDG saturation levels would be reduced by up to 20% saturation from present conditions as a result of the discharge through the turbines. Maximum TDG levels are expected to be less than 115% saturation. The higher tailwater elevation (i.e., el. 424 m) below the Hugh Keenleyside Dam after completion of the Murphy Creek Project also is expected to result in a significant reduction in the TDG levels in water passing through the sluiceway (IEC 1981) since the differential between the sluiceway crest (el. 424.9 m) and the tailwater (el. 424 m) will be only 0.9 m. This is expected to reduce the amount of air entrained in water passing over the sluiceway, and likely would reduce the depth to which the water and entrained air are carried in the plunge pool (i.e., due to reduced velocity upon entry into the plunge pool). As a result, total dissolved gas levels are expected to be

substantially lower during the powerplant operation (in conjunction with the Murphy Creek Project) than during present conditions.

The Keenleyside generating facilities would be shut down about 21 to 37% of the time because of insufficient head resulting from the required evacuation of the Arrow Lakes Reservoir for flood control purposes (B.C. Hydro 1982). Although no flow will be passing through the turbines during this period, the low head differential between the forebay and the tailwater will allow discharge to occur primarily through the low level ports (at very high discharges some water may need to be released through the sluiceway). Since water discharged through the ports does not become excessively supersaturated, high TDG levels should not be a problem during the period when the powerplant is shut down, providing that the low level ports are utilized as the primary mode of discharge.

Although high TDG levels are known to be harmful to fish held in shallow water (see Section 3.2.1.3), the effects on fish under natural conditions (i.e., where they can sound to a greater depth where they benefit from hydrostatic compensation) is less well understood. Since it is not presently known to what extent high TDG levels in the Columbia River within the study area cause mortality or affect the growth rates of fish, it is not possible to quantify the likely benefits of the reduction of TDG levels as a result of inclusion of generating capacity at the Hugh Keenleyside Dam. However, it is expected that the reduction of the high TDG saturations would have a beneficial effect on downstream fish populations since it would allow the sportfish species to spend longer periods of time feeding in shallow water areas which are generally more productive than the deeper areas. Also, since high TDG levels can cause gas bubble disease in benthic macroinvertebrates (Weitkamp and Katz 1980), a reduction of the high TDG levels in the Columbia River may result in increased benthic invertebrate production in the shallow water areas, thereby increasing the abundance of food organisms available to sportfish.

SECTION 5
MITIGATION AND COMPENSATION OPPORTUNITIES

5.1 CONSTRUCTION PHASE

5.1.1 SEDIMENT LOADS

Strict precautions should be taken to ensure that sediment input to Lower Arrow Lake and the Columbia River is minimized during the construction period. Methods to reduce sediment inflow as discussed by Sciandrone (1974) include riprapping unstable slopes, use of rock material rather than soil for fill and control of erosion on slopes by seeding, mulching, blankets, or binders. Wherever possible, borrow areas should be located well away from active stream channels. Runoff or effluents which have high suspended sediment concentrations (e.g., aggregate washing operations) should be diverted to settling or filter ponds. Settling ponds should be dredged when necessary, and the sediment removed to an appropriate disposal site.

To ensure that adequate precautions are taken to control erosion and the input of sediment into the aquatic system, strict guidelines should be written into the construction contracts. An environmental inspector should be present onsite during the construction period to ensure that the guidelines are followed. Also, biological monitoring should be conducted during the construction period to assess the effects of the construction activities on downstream aquatic biota.

5.1.2 WATER QUALITY

Spills or discharges of waste materials such as cement, gas, oils, greases, salts, untreated sewage, and chemicals could affect the water quality downstream of the construction site. To ensure that deleterious materials that may affect fish and other aquatic life do not enter the watercourse, strict guidelines and regulations relating to storage and disposal methods should be an integral part of construction contracts. Also, contingency plans in the event of a spill should be prepared and agreed upon by the contractors prior to beginning construction. All fuel storage and vehicle service areas should be located well away from the Columbia River. Berms should be constructed around all fuel storage or chemical storage areas to contain any accidental spill. An environ-

mental inspector should be onsite during the construction period to ensure the guidelines are followed.

5.1.3 USE OF EXPLOSIVES

The use of underwater explosives could result in high mortalities to fish located in the vicinity. Whenever feasible, excavation using explosives should be conducted "in the dry." Where the use of underwater explosives is necessary, precautions should be taken to minimize the effects on fish. These may include the following (Renewable Resources Consulting Services Ltd. 1978):

- burying the charge as deep as possible into the substrate;
- having major detonations as a series of successive charges with sufficient time in between the firing to allow dissipation of most of the shock wave; and
- dispersing concentrations of fish in the area by use of sonic or electrical shock.

With the limited use (if any) of underwater explosives expected during the Keenleyside Powerplant Project, and with monitoring to ensure that concentrations of fish are not present in the immediate blasting area, the numbers of fish that would be affected are expected to be small.

5.1.4 INCREASED ANGLING

During the construction period, the angling pressure exerted by the project staff should be monitored, especially in the vicinity of the construction camp. If it is evident that fish stocks are being depleted by anglers, then it will be necessary to identify the problem to the B.C. Fish and Wildlife Branch so that they may implement appropriate management measures (e.g., specific area and season closures; reduction of catch limit). If angling restrictions are instituted to protect the fish populations in the area, B.C. Hydro should assist where possible in the enforcement of the regulations (i.e., through educational programs, employee contract stipulations, etc.).

5.2 OPERATIONAL PHASE

5.2.1 SLUICEWAY RELEASES

From the available information it appears that high total dissolved gas concentrations occur downstream of the Hugh Keenleyside Dam, primarily during periods of high discharge through the sluiceway. Although the extent of supersaturation is expected to decrease throughout much of the year with the inclusion of generation facilities at the Hugh Keenleyside Dam, high levels likely still would occur whenever large volumes of water are discharged through the sluiceway. In order to reduce the extent of gas supersaturation downstream of the dam, water should be discharged through the generating facility or through the low level ports whenever possible, thereby minimizing the use of the sluiceway.

5.2.2 FISH ENTRAINMENT

A number of measures have been developed to prevent or minimize losses of fish at turbines; several of these techniques have been summarized by Ruggles and Collins (1981). In many cases, these techniques have been expensive and unreliable. Most have been designed for implementation during large downstream migrations of juvenile anadromous fish, with known behaviour and migration timing. Conditions at the Hugh Keenleyside Dam are complicated because a smaller, but unknown number of resident fish are involved, and no information is presently available regarding their behaviour and movements.

Several potential techniques are described below in terms of their practicality for the Keenleyside Powerplant Project.

5.2.2.1 Turbine Operation

As indicated by Bell et al. (1967) it is difficult to recommend specific changes to minimize fish losses during passage because of the normal design and restricted method of operation of turbines. In addition, many techniques may not be practical from a power generation viewpoint. However, a few operation methods may be feasible and are outlined below.

(a) Available data show that turbines with a negative pressure in the draft tube have a higher kill rate than those with positive pressures (Bell et al.

1967; Ruggles and Collins 1981). Thus, for plant operations, the highest possible tailwater level should be maintained. If peak downstream migration/passage times can be determined, highest levels (i.e., reduced daily or weekly fluctuations) need only be maintained for this period.

(b) If a period of significant downstream passage can be defined, the blade settings for the Kaplan turbine should be maintained at the general point of maximum efficiency for the turbine during this period. Studies have shown that highest fish survival occurs at the point of highest total operating efficiency (Turbak et al. 1981).

5.2.2.2 Fish Screening

Water intakes often can be screened to prevent loss of downstream moving fish. These screening techniques can take the form of physical barriers (i.e., travelling screens, bar screens), behavioural barriers (i.e., electrical stimuli, light, air bubbles, flow and velocity changes by using louvers) and fish bypass and collection systems.

Although a majority of these techniques appear impractical for the Keenleyside Powerplant Project, it may be possible to implement a floating screen deflector system across the top of the powerplant approach channel and divert fish towards the low level ports or sluiceway. However, the success would be questionable, as the behaviour of fish attracted to the outlets is unknown. A high proportion of fish likely will utilize the sluiceway or ports (when discharging) without screening or deflector provisions at the intake channel. Semple and McLeod (1976) found that although 72% of Atlantic salmon smolts were guided by deflector screens to a surface discharge bypass, nearly 50% used the bypass without the deflector. A floating screen device for the Hugh Keenleyside Dam would have to be large (i.e., 230-m length) and thus expensive; also, debris and maintenance problems may occur as a result of yarding of logs immediately upstream in the reservoir.

It is highly unlikely that screening of the Keenleyside Powerplant turbine intakes would be cost effective as the numbers of fish passed are probably small. Recruitment to the downstream fishery may even be decreased by screening unless fish were effectively guided to artificial outlets or the discharge ports.

5.2.3 ENHANCEMENT OPPORTUNITIES

Following is a discussion of potential opportunities that exist for increasing sportfish production in Lower Arrow Lake and in the Columbia River below the Hugh Keenleyside Dam. These enhancement opportunities are not specifically tied to the Keenleyside Powerplant Project, but rather, are presented as opportunities for increasing angling yields in the existing and proposed reservoirs within the study area.

The B.C. Fish and Wildlife Branch is presently investigating potential fisheries enhancement options for Lower Arrow Lake. The option that has been identified as having the greatest potential for increasing fish stocks in the system is the provision of fish passage facilities at the falls on the Inonoaklin River. This would give fish from Lower Arrow Lake access to some 32 km (and possibly as much as 50 km) of high quality spawning and rearing habitat (H. Andrusak, pers. comm.). The B.C. Fish and Wildlife Branch feels that this system may support an additional spawning escapement of approximately 1 000 000 kokanee, plus additional rainbow trout and Dolly Varden. The project would involve the construction of a fishway with a multiple level inlet to allow fish passage over an approximately 3-m-high falls, and an adjacent falls that varies in height from 1.2 to 12.2 m depending on the level of the Arrow Lakes Reservoir (H. Andrusak, pers. comm.). The design of a fishway that will be effective in passing fish throughout the wide variations in water level at the inlet has met with considerable problems; however, a design apparently is near completion.

Other potential options that may be suitable for enhancement of sportfish stocks in Lower Arrow Lake that have been identified by B.C. Fish and Wildlife Branch include the construction of spawning channels in tributaries such as Snow, Burton, or Caribou creeks, or the construction of a mini-hatchery on one of the tributaries in the area (H. Andrusak, pers. comm.).

Enhancement of fish stocks in Lower Arrow Lake likely would have a beneficial effect on fish stocks in the proposed Murphy Creek Reservoir. This would occur as a result of both decreased angling pressure within the Murphy Creek Reservoir (i.e., more people would fish in Lower Arrow Lake instead of in

the Murphy Creek Reservoir), and increased recruitment of fish to the Murphy Creek Reservoir through displacement from Lower Arrow Lake.

Since it is assumed that the majority of the kokanee that contribute to the sportfishery in the Columbia River below the Hugh Keenleyside Dam originate from stocks in Lower Arrow Lake (i.e., via passage through the dam - see Section 3.2.2.2), enhancement of the kokanee stocks in Lower Arrow Lake likely would increase the numbers of fish entrained at the Hugh Keenleyside Dam. Any increased numbers of kokanee passing through the dam and rearing in the upper Columbia River (or proposed Murphy Creek Reservoir) would be expected to contribute to the sportfishery in the area. A similar situation likely would exist for the other sportfish species (e.g., rainbow trout, Dolly Varden) that also may be enhanced in the Lower Arrow Lake, but the extent to which these stocks contribute to the fishery below the Hugh Keenleyside Dam is unknown.

SECTION 6
DATA DEFICIENCIES AND RECOMMENDATIONS FOR FURTHER STUDY

6.1 SUPERSATURATION

Total dissolved gas (TDG) saturation levels in the Columbia River below the Hugh Keenleyside Dam periodically reach levels that would be lethal to fish remaining at shallow depths. Although TDG concentrations are expected to be reduced when discharge occurs through low level ports or turbines, water will still be discharged through the sluiceway during certain periods. Additional studies should be undertaken to determine the precise operating conditions that lead to the high TDG levels and the distributional effects (vertical and horizontal) that high TDG saturation levels have on sportfish. The studies also should be designed to determine the extent to which the fish populations in the lower Columbia River are being affected by "gas bubble disease." It also would be useful to know the extent to which fish avoid problems related to the high TDG saturation levels by remaining deep in the water column, or if the fish spend short periods of time in the shallows to feed but return to deep water before substantial problems develop. Since high TDG levels may still occur periodically downstream of the Hugh Keenleyside Dam (i.e., when high sluiceway releases are required), mortalities may result if the fish do not avoid the shallow areas.

6.2 ZOOPLANKTON

A study should be initiated to determine the effect of **Mysis relicta** on fish production in Arrow Lake Reservoir and in the Columbia River. Although general observations of mysids have been made in the lake (on water intake screens upstream from the Hugh Keenleyside Dam) and in the Columbia River (Ash et al. 1981), no study has focussed on the importance of mysids to the diet of fish. The study also should document current patterns in front of the sluiceway and low level ports at various reservoir elevations, thermal regimes, and discharge to determine their effects on zooplankton entrainment (e.g., entrainment may be related to current velocity in front of the sluiceway or ports which may vary at different discharges and reservoir elevations, and may be affected by the passage of water through the generating facility).

6.3 FISH ENTRAINMENT AT THE HUGH KEENLEYSIDE DAM

No information is currently available relating to the extent, timing, size of fish, or mechanism of fish entrainment at the Hugh Keenleyside Dam. Without this information, it is not possible to accurately assess the impact of the addition of generating facilities on recruitment to the lower Columbia River or proposed Murphy Creek Reservoir. A field study should be conducted to determine the vertical distribution of fish in front of the Hugh Keenleyside Dam outlets (i.e., sluiceway, low level ports, boat lock) both seasonally and diurnally. High quality scientific echo sounding equipment likely would be required to conduct the study. This would allow an assessment of the probable extent (as a percentage) of entrainment between the low level ports and the spillway. In conjunction with this study, an assessment should be made of the species composition of fish in the vicinity of the discharge structures, and the size of the fish during the various seasons. Once the species of fish and size range are known, it may be possible to conduct mortality tests to determine the survival of fish moving through the spillway and low level ports. This information could then be used in conjunction with the Keenleyside Powerplant design specification to more accurately determine the likely overall effect of the project on downstream fish passage and recruitment to the Columbia River.

6.4 ASSESSMENT OF FISH SPECIES ABUNDANCE AND HABITAT USE OF LOWER ARROW LAKE NEAR THE HUGH KEENLEYSIDE DAM

Available fisheries information for Lower Arrow Lake is presently limited to an assessment of spawning escapements and habitat assessments in tributaries. In order to better define the species of fish which could be affected by the project, seasonal gill net sampling should be conducted in Lower Arrow Lake near the Hugh Keenleyside Dam. In conjunction with this, sampling should be conducted in the area to be physically disturbed by the project (i.e., at location of the cofferdam, intake channel, etc.) to determine the actual or potential use of these areas for spawning by reservoir fish stocks (e.g., lake whitefish, burbot, coarse fish species). The clean rock material used to protect faces of dams in other areas has been shown to be used for spawning by reservoir fish stocks (Grinstead 1971).

6.5 ASSESSMENT OF SPAWNING IN THE COLUMBIA RIVER IMMEDIATELY BELOW THE HUGH KEENLEYSIDE DAM

Present information indicates that spawning use of the upper section of the mainstem Columbia River by salmonids (i.e., rainbow trout, kokanee, Dolly Varden) likely is limited. However, a survey should be made (e.g., using SCUBA gear) to more precisely evaluate potential spawning habitat and use by these species in the section along the north bank of the river within the first few kilometres below the Hugh Keenleyside Dam. Due to the proximity of construction activities and the proposed construction camp to this area, it would have the highest potential for impact if isolated areas are being used for spawning.

6.6 MONITORING STUDIES

Upon completion of the Keenleyside Powerplant Project, monitoring studies should be conducted to determine the actual effects of powerplant operation on dissolved gas saturation levels, zooplankton entrainment, and fish entrainment and survival. These data then could be compared with pre-project data and predictions of impacts. This will facilitate a better understanding of these aspects of hydroelectric development, and improve the predicted capability for any future projects.

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Plate 1. Hugh Keenleyside Dam. The navigation lock is on the left side of the photo, and the four sluiceway gates (one partially open) are in the centre. Four low level ports are visible on each side of the sluiceway. The proposed generation facilities would be located to the right of the photograph.

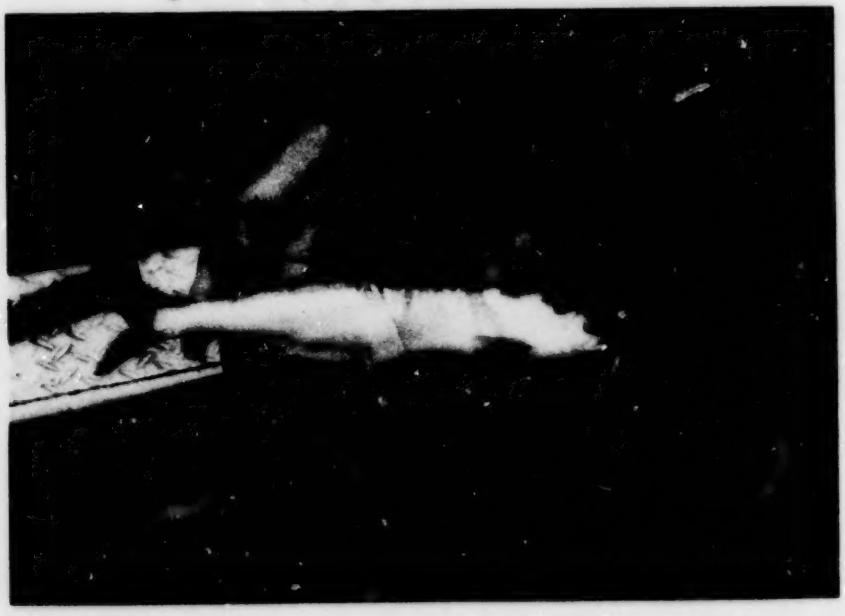

Plate 2. Kokanee captured immediately below Hugh Keenleyside Dam. This fish is typical of kokanee in the Columbia River between Castlegar and the Hugh Keenleyside Dam, and also in Lower Arrow Lake.

Appendix A

TERMS OF REFERENCE

3 February 1982

KEENLEYSIDE POWER GENERATION

Terms of Reference
ENVIRONMENTAL STUDIES

1.0 INTRODUCTION

Prior to signing the Columbia Treaty in 1961 and its ratification in 1964, numerous studies were made of the hydroelectric development of the Columbia River in Canada. The Treaty between the United States and Canada led to the construction of Mica and Hugh Keenleyside projects on the Columbia River in Canada. The Revelstoke project on the Columbia, now under construction, is not a Treaty project.

Keenleyside dam was constructed at the outlet of Lower Arrow Lake near Castlegar, above the confluence of the Kootenay River. The project, completed in 1968, was for the purpose of water storage and contained no power generation facilities.

Since 1977, B.C. Hydro has been studying the Murphy Creek project, which would be located on the Columbia River, 35 km downstream of Keenleyside dam. Three reservoir elevations were studied; the lowest level (424 m) would allow the installation of a powerhouse at Keenleyside. The Murphy Creek project, if built, would not be a Treaty project.

Environmental information on the proposed Murphy Reservoir has been collected for levels 430 m, 427 m and 424 m. These terms of reference are for detailed environmental studies of the addition of Keenleyside power generation to the Murphy Creek 424 m case. All environmental studies should assume Murphy 424 m and identify any changes or

incremental impacts caused by the Keenleyside project. All discussions should clearly specify the differences between the two scenarios.

The Keenleyside reports are intended to be read in conjunction with the Murphy Creek documents, and therefore should avoid duplication of baseline data wherever possible.

Information on the study area without further hydroelectric development, and on the impacts of Murphy 424 m, is available in existing Murphy Creek environmental reports.

Study objectives, organization, liaison and methodology are the same as described in the Murphy Creek terms of reference.

B.C. Hydro will supply information on project description and schedules, operating regime, and will make available environmental reports on Murphy Creek.

2.0 STUDY AREA

The study area consists of all lands and waters below 500 m elevation within 10 km of Keenleyside dam. The study area for fisheries should include the lower Arrow Reservoir and the future Murphy Creek Reservoir (or the Columbia River as far south as Trail). The study area for socio-economics and resource evaluation should include local communities of the Columbia Valley.

(a) Reporting Procedures

Written reports will be required for all sections of the studies. Five draft reports and 45 final reports will be required. Draft reports will be prepared and submitted for review by B.C. Hydro and, where necessary, by outside experts before they are accepted. All final reports shall be in a form suitable for release to government agencies and the public. Following completion of all

the reports for the sections, B.C. Hydro will prepare an integrated summary report in consultation with the authors of the sections and outside experts, where necessary.

(b) Studies Schedule

The studies will be undertaken in early 1982. A target schedule showing specific deadlines will be issued for each section.

(c) Studies Sections

The following are guidelines for each of the sections. These guidelines distinguish between inventory and assessment work. Where feasible this distinction should be made in report preparation.

Study sections are:

A Aquatic Resources
B Vegetation, Agriculture and Forestry
C Wildlife
D Heritage Resources
E Socio-economic Resources
F Recreation
G Land Use
H Water Use
I Resource Atlas
J Resource Evaluation

SECTION A - AQUATIC RESOURCES

1.0 OBJECTIVES

1. To describe potential changes to fisheries resources in Lower Arrow Lake and the proposed Murphy Reservoir (or Columbia River) resulting from the project.

2. To determine whether or not further field studies are necessary.

3. To suggest mitigation measures with respect to fisheries and aquatic impacts.

2.0 METHODOLOGY

(a) Inventory

1. Review the fish and aquatic habitats report for the proposed Murphy Creek project.

2. Assemble existing information including (but not limited to):

   a. relative abundance of fish species residing in the study area.

   b. areas used for spawning and rearing in the study area.

3. Assemble existing information on water quality parameters relating to fish (e.g. dissolved gases, temperature, nutrients) in Lower Arrow Lake and the Columbia River.

(b) Assessment

1. Identify how incorporation of generating facilities at Keenleyside dam would alter the impact assessment as made for the Murphy Creek project.

2. Identify any limnological changes which may occur in the Lower Arrow Lake and in the proposed Murphy Creek reservoir due to power generation at Keenleyside dam. This should include physical and biological parameters.

3. Identify any probable changes which might be expected to occur in the sport fishery in the study area.

4. Interpret the impact of changes in water quality parameters on aquatic resources in the study area.

5. Determine whether passage of fish through the generating facility would alter recruitment rates into the proposed Murphy Creek reservoir.

6. Determine what additional inventory information is necessary on water quality, fish and aquatic habitats of the Lower Arrow Lake and the Columbia River in the study area. Determine whether further field studies are necessary.

7. Recommend any readily identifiable mitigation and compensation measures to enhance aquatic resources in the study area. Briefly discuss possible increases (if any) to recruitment into the proposed Murphy Creek reservoir caused by potential enhancement of Arrow Lake fish stocks.

Appendix B

WATER QUALITY DATA

Table B-1. Depth profiles of temperature, dissolved oxygen, and specific conductance in Lower Arrow Lake, 14 September and 25 November 1976. (Source: B.C. Research 1977.)

14 September 1976 Secchi Depth = 7 m					25 November 1976 Secchi Depth = 11 m					
		Oxygen		Specific			Oxygen			Specific
Depth (m)	Temp. (°C)	Probe (mg/L)	Probe % Saturation	Conductance (µS/cm)	Depth (m)	Temp. (°C)	Probe (mg/L)	Winkler (mg/L)	Probe % Saturation	Conductance (µS/cm)
0	14.1	8.7	85	91	0	7.7	12.5	10.5	104	97
2	14.0	8.7	84	91	2	7.7	12.2	-	101	97
4	13.7	8.7	83	91	4	7.7	12.1	-	100	97
6	13.5	8.6	82	91	6	7.7	12.0	-	100	100
8	13.5	8.5	81	91	8	7.7	12.0	-	100	100
10	13.5	8.4	80	95	10	7.7	11.9	-	99	100
12	12.9	8.3	78	94	12	7.7	11.9	-	99	100
14	12.6	8.2	76	94	14	7.7	11.8	-	98	100
16	12.5	8.2	76	94	16	7.7	11.7	-	98	100
18	12.5	8.2	76	95	18	7.7	-	10.5	-	100
20	12.3	8.2	76	94	20	7.7	-	-	-	100
22	12.2	8.2	76	94	22	7.5	-	-	-	100
24	11.5	8.2	75	94	24	7.1	-	10.5	-	102
26	11.1	8.4	76	94	26	6.6	-	-	-	105
28	11.1	8.4	76	94						

Table B-2. Depth profiles of temperature and dissolved oxygen in Lower Arrow Lake near Syringa, 21 July, 18 August, and 15 September 1980. Dissolved oxygen data were not obtained in August. (Source: B.C. Ministry of Environment, EQUIS Station No. 0200524.)

21 July 1980			18 August 1980		15 September 1980		
Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/L)	Depth (m)	Temperature (°C)	Depth (m)	Temperature (°C)	Dissolved Oxygen (mg/L)
1.5	18.7	9.1	0.3	18.8	1	16.0	9.8
4.6	18.3	8.8	1.5	18.8	5	15.9	9.8
7.6	18.2	8.9	3.0	18.7	10	15.1	9.6
10.7	17.7	8.9	4.6	18.6	15	12.7	9.6
13.7	17.2	8.6	6.1	18.2	20	11.6	9.6
16.8	14	8.8	7.6	17.0	25	9.6	9.8
19.8	11.2	9.6	9.1	13.3	30	8.9	9.8
22.9	10	9.5	10.7	12.6	33	8.6	10.0
25.9	9.1	9.6	12.2	11.6	35	8.5	9.8
29	9.5	9.5	13.7	11.2			
32	8.8	9.6	15.2	9.8			
33	8.8	9.6	16.8	9.6			
			18.3	9.4			
			19.8	9.3			
			21.3	9.2			
			22.9	8.4			
			24.4	7.4			
			27.4	6.6			

Table B-3. Summary data on nutrients, dissolved solids, and metals for Lower Arrow Lake at all depths near Syringa, 1 January to 31 December 1980 (EQUIS Station 0200524). (Source: B.C. Ministry of Environment EQUIS Data; R. Crozier, pers. comm.)

	004 pH	005 Residue, 105°C mg/L	007 Filtered Residue, 105°C mg/L	008 Non-filtered Residue, 105°C mg/L	011 Specific Conduct. µS/cm	015 Turbidity N.T.U.	024 Colour T.A.C.	102 Alkalinity mg/L	103 Carbn Or mg/L	104 Chloride mg/L	106 Fluoride mg/L	107 Hardness mg/L
No. of Values	12	4	4	2	8	6	4	2	6	2	2	2
Maximum	8.4	70	68	2	130	0.5	1	50.5	1	0.5	0.1	55.2
Minimum	7.8	56	54	2	91	0.3	1.	43.1	1	0.5	0.1	45.9
Average	8.1	63	61	2	109.37	0.4	1	46.8	1	0.5	0.1	50.55
S.D.	0.17579	6.2183	6.2183	0.0	14.121	0.089443	0.0	5.2326	0.0	0.0	0.0	6.5761

	108 Ammonia mg/L	109 NO_2/NO_3 mg/L	113 Nit Kjel mg/L	118 Phos ort mg/L	119 Phos Tot mg/L	120 Silica mg/L	121 Sulphate mg/L	143 Chloro A mg/L	146 Phaeo A mg/L	251T Arsenic, Total mg/L	253T Cadmium, Total mg/L
No. of Values	6	6	6	6	6	4	2	15	15	2	2
Maximum	0.013	0.18	0.22	0.005	0.005	3.9	7	0.0022	0.0005	0.005	0.0005
Minimum	0.005	0.08	0.08	0.003	0.003	3	6.5	0.0005	0.0005	0.005	0.0005
Average	0.0066333	0.12333	0.165	.0033333	.0041667	3.475	6.75	0.0012667	0.0005	0.005	0.0005
S.D.	0.0032506	0.045898	0.061237	.0008165	.0009832	0.44253	0.35355	0.000508	0.0	0.0	0.0

	254D Calcium Dissolved mg/L	256T Copper Total mg/L	257T Iron Total mg/L	258T Lead Total mg/L	259D Magnesium Dissolved mg/L	260T Manganese Total mg/L	264D Potassium Dissolved mg/L	265D Sodium Dissolved mg/L	266T Zinc Total mg/L
No. of Values	4	4	2	4	4	2	2	2	4
Maximum	16.5	0.001	0.1	0.001	3.4	0.02	0.6	0.9	0.015
Minimum	14.1	0.001	0.1	0.001	2.2	0.02	0.6	0.9	0.005
Average	15.3	0.001	0.1	0.001	2.775	0.02	0.6	0.9	0.0075
S.D.	1.0954	0.0	0.0	0.0	0.5058	0.0	0.0	0.0	0.005